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The Effects of Applications of Phosphorus and Zinc on Growth and Nutrientuptake by Rice, Oryza Sativa L., Cultivar Saturn.

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THE EFFECTS OF APPLICATIONS OF PHOSPHORUS AND ZINC ON GROWTH AND NUTRIENT UPTAKE BY RICE, *ORYZA SATIVA* L., CULTIVAR SATURN

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ABSTRACT

A greenhouse investigation was conducted on unlimed and limed Crowley silt loam to determine the effects of applications of phosphorus and zinc on the production of dry matter of rice, Oryza sativa L., cultivar Saturn, at different phases of growth and development. The effects of applications of phosphorus and zinc on the concentration and uptake of zinc, on the ratio of the concentration and uptake of phosphorus and zinc by Oryza sativa L., cultivar Saturn, were also studied. Another investigation was conducted to determine the effects of applications of zinc and different sources of phosphorus on the production of dry matter and on the concentration and uptake of phosphorus and zinc in plant tissue of Oryza sativa L., cultivar Saturn, at the vegetative phase of growth and development on unlimed Crowley silt loam, pH 5.3.

There was no interaction between phosphorus and zinc in the production of dry matter, the concentration and uptake of phosphorus and zinc by rice plants grown on unlimed Crowley soil, pH 5.3. The application of phosphorus to the unlimed soil resulted in an increase in the production of dry matter and the concentration and uptake of phosphorus, but it did not reduce the zinc concentration in the plant tissue. The application of zinc did not have a significant effect on the production of dry matter of rice plants grown on the unlimed soil.

A significant interaction was found between phosphorus and zinc in the production of dry matter and in the concentration and

uptake of phosphorus and zinc by rice plants grown on the limed Crowley soil, pH 6.3. The application of phosphorus to the limed soil resulted in a significant increase in the production of dry matter and the concentration and uptake of phosphorus by the rice plants. Evidence was obtained which indicated that a high rate of applied phosphorus depressed the concentration of zinc in the tissue of rice plants grown on limed Crowley silt loam soil. The application of zinc to the limed soil resulted in a significant increase in the production of dry matter and the concentration and uptake of zinc in the tissue of the rice plants.

When no zinc was applied, normal superphosphate was found to be superior to concentrated superphosphate, diammonium phosphate and monoammonium phosphate, but it was not better than ammonium polyphosphate in the production of dry matter. When zinc was applied, normal superphosphate and ammonium polyphosphate were superior to the other sources of phosphorus in dry matter production of rice plants. The application of concentrated superphosphate with or without zinc resulted in the highest concentration of phosphorus in the rice tissue. The application of all of the sources of phosphorus resulted in a depression in the concentration of zinc in the plant tissue. The largest amount of phosphorus taken up by the rice plants occurred on the soil that received an application of normal superphosphate or ammonium polyphosphate. The application of normal superphosphate resulted in the largest amount of zinc taken up by the rice plants.

INTRODUCTION

Many investigators have reported that large applications or prolonged usage of phosphorus fertilizer have resulted in decreased zinc uptake or even induced zinc deficiency in upland crops on certain soils (9, 13, 20, 41, 50, 52, 56, 57). However, other workers have not obtained a significant interaction between phosphorus and zinc (6, 11, 49). Undoubtedly, the effect of phosphorus on zinc uptake will vary with the particular soil and crop involved, with the levels and solubilities of zinc and phosphorus in the soil, and with other chemical properties of the soil, - namely, soil reaction, cation exchange capacity, per cent base saturation, and the content of organic matter.

Liming coarse-textured acid soils frequently induces zinc deficiency (35, 49, 71). Zinc deficiency has also been reported on calcareous soils in various parts of the world (22, 77). The solubility of zinc is greatly reduced when the soil reaction approaches neutrality (50). Melton, Ellis and Doll (35) reported that liming induced zinc deficiency in Phaseolus vulgaris, and when a heavy phosphorus application accompanied the lime treatment, a greater zinc deficiency occurred.

The effects of applications of phosphorus and zinc on the uptake of these nutrient elements by rice grown on submerged soils have not been thoroughly investigated. A greenhouse experiment conducted by plant physiologists at the International Rice Research Institute in the Philippines indicated that a heavy application of phosphorus to two different soils, one acid in reaction, pH 5.8, and the other alkaline, pH 8.7, did not cause zinc deficiency in rice plants growing under submerged conditions. However, phosphate application resulted in decreased zinc content in rice plants grown under upland conditions (27).

An experiment was initiated at the Rice Experiment Station at Crowley, Louisiana in 1959 to determine the effects of four rates of phosphorus, 0, 40, 80 and 160 pounds of P per acre, on the yield of rice grown on Crowley silt loam, pH 5.7, under submerged conditions. Initially, the soil contained only 6 ppm of dilute acid extractable phosphorus. The yield data obtained in 1960 and 1961 indicated that the higher rates of phosphorus resulted in lower yields of rice.

Since soil reaction (pH) and application of phosphorus are important factors affecting the solubility and subsequent uptake of zinc by many plants, this investigation was initiated on Crowley silt loam with the following objectives: (1) to determine the effects of applications of phosphorus and zinc on the production of dry matter and the nutrient composition and uptake by *Oryza sativa* L., cultivar Saturn, grown under submergence on unlimed Crowley silt loam, pH 5.3, and on Crowley silt loam that was adjusted to pH 6.3 with calcium carbonate and (2) to determine the effects of five different sources of phosphorus; normal superphosphate, concentrated superphosphate, diammonium phosphate, ammonium polyphosphate and monoammonium phosphate on the production of dry matter, and the nutrient composition and uptake by *Oryza sativa* L., cultivar Saturn, grown under submergence on unlimed Crowley silt loam, pH 5.3.

REVIEW OF LITERATURE

Zinc deficiency of pecans was first described and corrected in 1932 by Alben, Cole and Lewis (4) at the USDA pecan research station at Robson, Louisiana. These investigators used zinc sulfate or zinc chloride to correct pecan rosette, an abnormality caused by insufficient amount of soluble zinc in the soil. It is interesting to note that even though these investigators did not associate the zinc deficiency of pecans with phosphorus, the levels of phosphorus in the soil where severe rosette occurred were relatively high. In 1937, Chapman, Vanselow and Liebig (21) reported that large applications of phosphorus induced zinc deficiency symptoms in Valencia orange seedlings grown in nutrient solutions under controlled conditions. A year later, West (76) demonstrated that zinc corrected mottle-leaf in citrus which was induced by the excessive usage of phosphorus.

During the decade following the investigation conducted by West, only a limited amount of research was conducted on the zinc-phosphorus interaction phenomenon. In 1948, Rogers and Chih-Hwa-Wu (49) presented data which indicated that the zinc content of oats was decreased with increasing rates of applied phosphorus. However, Bingham (6) reported that he could not produce zinc deficiency in beans, corn, tomatoes and sour orange seedlings grown in sand culture with as much as 100 ppm of phosphorus and 0.05 ppm of zinc. Loneragan (33) using flax as an indicator plant noted that zinc deficiency symptoms appeared four weeks after seeding when high amounts of phosphorus were applied. Burleson and Page (17) also used flax as an indicator plant and they concluded that the zinc-phosphorus interaction occurred at the root surfaces or within the plant. They concluded that phosphorus and zinc reacted together within the root in a manner that reduced either their mobility or solubility. Boawn and Leggett (10) reported that increasing the supply of phosphorus induced a growth disorder in Russet Burbank potato and the disorder was eliminated by increasing the supply of zinc. The data indicated a mutual antagonism between phosphorus and zinc in their uptake and accumulation in the plant. Later, Boawn and Brown (8) reported that phosphorus induced zinc deficiency in beans (*Phaseolus vulgarus* L.) and potatoes (*Solanum tuberosum* L.) without causing a decrease in the zinc content of the plants. Increasing the level of zinc in the soil at a given phosphorus level resulted in plants with normal growth.

Burleson, Dacus and Gerard (18) noted severe zinc deficiency of Red Kidney beans when phosphorus was applied to the soil. Ellis, Davis and Thurlow (23) pointed out that in most of their experiments, a negative correlation was calculated between zinc and phosphorus concentration in plant tissue. In one experiment, applications of 437 and 655 pounds per acre of phosphorus decreased the zinc concentration in field beans and corn.

Martin, McLean and Quick (35) noted that phosphorus applications reduced the zinc concentration in the leaf tissue of potato plants while the zinc applications tended to reduce the phosphorus concentration in the leaves. Dwarfed plants exhibiting acute zinc deficiency symptoms had approximately the same zinc and phosphorus concentration on the dry weight basis as did normal plants grown at a higher soil temperature.

According to Melton, Ellis and Doll (37), heavy applications of phosphorus generally induce a greater zinc deficiency on soils that are neutral to alkaline in reaction. On acid soils, the yields of pea beans were decreased when zinc was applied, however liming the soils induced zinc deficiency.

Paulsen and Rotini (43) observed that high phosphorus levels decreased the growth of a phosphorus-sensitive variety of soybeans more than it did a phosphorus-tolerant variety, but it decreased the zinc concentration in both varieties. They also observed that the interaction of phosphorus with zinc resulted in a decreased concentration of zinc in the leaves.

Penas and Sorensen (44) reported a significant interaction between zinc and phosphorus on the growth and composition of corn grown in nutrient solutions. Increasing the levels of phosphorus and zinc in the nutrient solution had a much more pronounced effect on plant growth than did increased levels of iron and manganese.

Sharma, Krantz, Brown and Quick (54) observed zinc deficiency in corn and tomatoes grown in Corning and Landlow soils. They noted that the concentration of zinc in the above ground tissue of both crops was reduced due to phosphorus applications. The concentration of zinc in the roots was much less influenced by the phosphorus treatments. In another experiment conducted by Sharma et al. (53), applications of phosphorus markedly decreased the concentration of zinc in the leaves of wheat, however, it was noted that the pattern of zinc deficiency symptoms was very different in the two varieties of wheat used in the investigation.

Ward et al. (70) stated that zinc deficiency may be aggravated or created by a relatively low rate of phosphorus applied in a band or by a larger rate of phosphorus applied broadcast to the soil and mixed in the row. Phosphorus induced zinc deficiency appears to be a greater problem on calcareous soils and especially on those soils that are inherently high in indigenous phosphorus and low in soluble zinc. Ward et al. (70) concluded that the more effectively the applied phosphorus is utilized by corn and grain sorghum, the more severe is the reduction in zinc utilization.

The results of research conducted by Warnock (72) indicated that applied phosphorus reduced the zinc concentration in the tissue of corn but it did not reduce the zinc uptake per plant. Warnock (72) also noted that zinc deficient plant accumulated a large excess of iron. Interference from excessive amounts of iron was suggested as contributing to physiological malfunction within zinc-deficient corn plants.

Factors Affecting the Interaction of Phosphorus and Zinc in Plants

Many investigators have reported that the relationship between phosphorus and zinc is influenced by plant species (1, 2, 15, 18), soil temperature (23, 24, 35, 55), sources of phosphorus (2, 24) and by method of applying phosphorus, soil compaction and soil moisture (71).

Brown and Tiffin (15) found that certain species of plants were more susceptible to a deficiency of zinc than were others. Red Kidney beans, okra and tomatoes developed severe zinc deficiency symptoms and responded to an application of zinc. Zinc deficiency also developed in corn, however, with the application of 97 ppm of zinc to the soil, an iron chlorosis was observed. The corn plants developed normally when 40 ppm of zinc was applied. The addition of phosphorus accentuated zinc deficiency in all of the crops and also caused iron chlorosis in _Zea mays_ and _Sericea_ _lespedeza_. Zinc deficiency was not observed in soybeans, barley and wheat grown on Tulare clay soil. According to Brown and Tiffin (15), Viets et al. rated several plant species as to their susceptibility to zinc deficiency. Bush beans, hops and flax were more susceptible to a deficiency of zinc than were barley, wheat, mustard, carrots, peas and rye.

Adriano and Murphy (1) found a different pattern of phosphorus-zinc interaction in corn and in navy bean seedlings. High rates of phosphorus depressed zinc translocation from the roots to the shoots in corn seedlings. In bean seedlings, the high rates of phosphorus increased the zinc as well as the phosphorus concentration in the tissue. The application of high rates of phosphorus induced zinc deficiency symptoms in the saginaw variety of bean, however, the authors reported that the deficiency of zinc was not associated with a low concentration in the plant tissue.

Ellis et al. (23) stated that the yield, the zinc concentration in the plant tissue and the total zinc uptake by corn was significantly reduced when the soil temperature was decreased from 75 ^{o}F to 55 ^{o}F.

The results of an experiment conducted by Ganiron et al. (24) indicated that the growth of Zea mays L. seedlings in solution cultures responded to soil temperature, rate of zinc, source of phosphorus and to the source of zinc. Phosphate accumulated in the root and shoot of zinc deficient seedlings at the higher temperature but was depleted from the root when the seedlings were supplied with zinc. Almost similar zinc concentrations were present in the root and shoot of the seedlings grown at the lower temperature. The data suggested that temperature affected the availability of soil zinc more than it did the uptake or translocation of zinc.

Martin et al. (35) found that the application of phosphorus to a soil that was considered to be moderately low in extractable zinc induced zinc deficiency in tomato plants when the soil temperatures were 50°F and 60°F, however zinc deficiency symptoms were not noted when the soil temperatures were elevated to 70°F and 80°F. In a soil from an area that was found to be critically deficient in zinc, the application of phosphorus induced zinc deficiency at all temperatures.

Sharma et al. (55) used rice (*Oryza sativa* L.) as an indicator crop in the greenhouse to study the interactions of zinc and phosphorus with soil temperature in a Corning clay loam soil. They reported that a decrease in soil temperature from 30°C to 22.5°C and to 15°C gave a progressive decrease in the dry weight of rice plants. It was also noted that the response to zinc decreased with increasing soil temperatures. When the temperature was adjusted to 15°C, application of zinc increased the zinc concentration in the roots but there was practically no translocation of the zinc to the tops. Furthermore, at the lowest temperature, the concentration of zinc in the tops of the rice plants grown with added zinc was even lower than the zinc concentration of plants that did not receive zinc at 22°C and 30°C.

Adriano and Murphy (2) found that banded applications of ammonium polyphosphate in the presence of inadequate amounts of soluble zinc in Cass fine sandy loam soil tended to induce more severe zinc deficiencies in *Zea mays* L. than did similar applications of monoammonium phosphate. When adequate zinc was supplied, the two sources of phosphorus produced comparable plant growth responses in grain yield. Yield depressions noted with the use of banded ammonium polyphosphate without adequate zinc were associated with high plant phosphorus content than when the plant was supplied with monoammonium phosphate.

Adriano and Murphy (2) also noted that high levels of plant phosphorus were concomitant with low levels of zinc in corn plants. Banded applications of phosphorus resulted in higher concentrations of phosphorus in the plant tissue than did broadcast applications of phosphorus and induced more severe zinc deficiency. When zinc was limiting, grain yields tended to decrease with increasing phosphorus concentrations in plant tissues. In the presence of adequate zinc, concentration of phosphorus in young plant tissues was positively correlated with grain yields.

Ganiron et al. (24), using solution cultures reported that monoammonium phosphate was slightly more favorable for the growth of _Zea mays_ L. than was ammonium polyphosphate, but ammonium polyphosphate increased the phosphate uptake more than did the monoammonium phosphate.

Ganiron et al. (24) also found that phosphorus depressed corn grain yield when the levels of zinc in the soil were low. Applying zinc increased grain yields only to the levels obtained without phosphorus fertilization. Concentrations of phosphorus in the leaves of corn varied inversely with the rate of zinc fertilization, but concentrations of zinc were not affected markedly by the treatments. Ammonium polyphosphate and chelate zinc were only slightly better sources than were monoammonium phosphate and zinc sulfate.

Ward et al. (71) using corn as an indicator plant found that fertilizer phosphorus applied in a band in the row markedly reduced the concentration of zinc in the plant tissue. Increasing both soil compaction and soil moisture level caused a further depression of zinc concentration in the corn plant. It was concluded by the authors that the combination of irrigation and application of phosphorus on newly graded and compacted soil, especially when the level of soil phosphorus was high would probably result in zinc deficiency problem.

Ward et al. (71) also reported that potassium saturation of a soil appeared to have a decided influence on phosphorus-zinc relations in plants. It was noted that the higher the per cent potassium saturation of the soil, the less did applied phosphorus reduce plant uptake and utilization of zinc. A highly significant positive correlation coefficient, $r = 0.847$, was calculated for phosphorus-zinc and potassium saturation.

Critical Level of Zinc in Plant Tissue

According to Robinson et al. as reported by Chapman (19), the zinc content of plants ranges from 20 ppm to over 10,000 ppm. Many plants contain less than 20 ppm of zinc. There is a considerable amount of research indicating that zinc readily accumulates in the leaves of certain plants in considerable amounts. This range in the zinc content of leaves, where deficiency is characterized by very low values and where excessive concentration by high values, provides the basic reason for the concept that the zinc content of the leaves of plants provides a sound basis for evaluating the zinc status of plants. According to Chapman (19) for a wide varieties of plants, deficiency of zinc has been noted when the level of zinc is less than 25 ppm in the dry matter. Ample or sufficient levels commonly fall in the range of 25 to 150 ppm. A concentration of zinc in plant tissue in amounts greater than 400 ppm may indicate zinc excess or even toxicity.

Apparently, the analysis for zinc in the plant tissue of rice is a very reliable indicator of the zinc status of the crop. The investigators at the International Rice Research Institute (28) reported that if the zinc content of the shoot of the rice plant at an early growth stage is less than 10 to 15 ppm, zinc deficiency is likely to occur. This is in agreement with the conclusion drawn by Ishizuka and Tanaka as reported by Yoshida and Tanaka (79) in which zinc deficiency symptoms were observed in rice when the concentration of zinc was less than 15 ppm on the dry weight basis.

Research conducted in Louisiana by Sedberry et al. (52) indicated that a yield response to applied zinc may be obtained when the concentration of zinc in the leaves of rice plants sampled when the panicle was 2 mm long was less than 15 ppm. However, it was noted that the ashing technique was important in establishing critical level of zinc in plant tissue. Consistantly lower values for zinc were obtained when the rice tissue was dry-ashed in a muffle furnace as opposed to acid digestion. Dry ashing of plant material invariably leaves a residue of silica which absorbs traces of micronutrient elements. This is particularly true of rice tissue which is relatively high in silica, and losses of zinc by absorption on silica may be as high as 25 per cent or more unless the silica is removed by treatment with hydrochloric acid.

Critical Level of Zinc in Soil

According to Swaine as reported by Chapman (19), the total zinc content of soils varies from 10 to 300 ppm. Preliminary data on file at the Department of Agronomy, Louisiana State University, indicates that the total zinc content of the soils of Louisiana ranges from 17 ppm to slightly over 100 ppm. Soils comprising areas within the coastal prairie section of the state contain a smaller amount of total zinc.

Alben et al. (4) reported that pecan trees grown on slightly acid soils exhibited symptoms of zinc deficiency when the total zinc content of the root zone was less than 68 ppm.

Brown et al. (14) found that zinc extracted from the soil with dithizone (Diphenylthiocarbazone) gradually decreased with cropping and when the concentration of zinc decreased to 0.55 ppm or lower, there was a growth response by corn to applied zinc. They proposed that 0.5 ppm of zinc extracted with dithizone was a critical level of zinc in the soil and a response in the growth of corn would be expected at this level of soil zinc.

Wear (74) conducted 25 field investigations involving the applications of zinc to different soils used for the production of corn. He reported that a response to zinc was not obtained when the pH of the soil was less than 5.9 or when the dithizone extractable zinc content of the soil was more than 0.90 ppm.

Sedberry et al. (52) reported that zinc deficiency in the rice grown on prairie soils in Louisiana frequently occurs when the zinc content of the soil determined by extracting the soil with 0.1 N hydrochloric acid, is about 1.2 ppm or below.

Phosphorus-Zinc Interaction

West (76) and Chapman (19) reported that large applications or prolonged usage of phosphate fertilizer will decrease zinc uptake and will cause zinc deficiency of various crops. However, other workers have reported no significant interaction between phosphorus and zinc

(11, 51). Apparently, the effect of phosphorus on the solubility and subsequent uptake of zinc by plants may vary with the type of soil and crop involved, with the zinc and phosphorus levels in the soil and with soil reaction.

Only a limited amount of research has been conducted on the phosphorus-zinc interaction in soils under submerged conditions. A preliminary investigation conducted by plant physiologists at the International Rice Research Institute (28) indicated that a heavy application of phosphorus did not result in zinc deficiency of rice in submerged soil. However, phosphorus application resulted in decreased zinc content in rice plants grown under upland conditions.

Boawn and Leggett (9) found a mutual antagonism between phosphorus and zinc in their uptake and accumulation in the leaf tissue of Russet Burbank potato plants. When the supply of phosphorus in the soil was increased, a plant growth disorder occurred and the disorder was eliminated by increasing the supply of soil zinc. Large concentrations of phosphorus in the leaf tissue resulted in a high phosphorus:zinc ratio and it was noted that normal plants contained phosphorus and zinc in a ratio of less than 400:1. Plants that did not grow normally and those that were deficient in zinc contained phosphorus and zinc in a ratio that exceeded 400:1.

Ellis et al. (23) presented data which supported the hypothesis that the phosphorus-zinc interaction occurred either at the root surface or within the root of corn plants.

Burleson and Page (17) grew flax in a growth chamber in an attempt to determine the nature of the interaction between phosphorus and zinc.

Zinc and phosphorus were added separately at different time intervals so that any interaction that occurred had to take place at the surface of the roots or within the flax plant. Nutrient solutions and a two zone root technique were employed to evaluate the type of interaction. When phosphorus was added first, zinc increased the total phosphorus in the lower and upper roots and decreased total phosphorus in the tops. When zinc was added first, the phosphorus increased the zinc in the lower roots and decreased zinc in the tops. The authors concluded that the results obtained indicated that phosphorus and zinc reacted together within the roots in a manner that reduced either their mobility or solubility.

Halim et al. (25) conducted zinc investigations under field conditions and in growth chambers using several inbred lines and single crosses of corn as indicator crops. The authors found that the degree and pattern of zinc deficiency symptoms varied with plant genotypes. Some of the inbred lines showed an early resistance to zinc deficiency, however they became susceptible at later stages of plant growth. Other lines were found to be susceptible at early stage of growth and became resistant later on. Single crosses of these lines resulted in high resistance to a deficiency of zinc. High phosphorus did not appear to reduce the uptake of zinc when lines were considered as a whole. However, high phosphorus appeared to reduce the dry weights of the plants. The authors concluded that the nature of the resistance to zinc deficiency appeared to be under genetic control.

Pauli et al. (42) established an investigation to determine the influence of calcium carbonate and phosphorus on the uptake and translocation of zinc by navy bean plants grown in sand cultures. Their results indicated that the addition of calcium carbonate decreased dry weights and the concentration of zinc in all of the plant parts. Calcium carbonate also decreased the translocation of zinc and increased the translocation of phosphorus from the roots to the leaves. The results suggested that the usage of excessive amounts of calcium carbonate influenced the phosphorus-zinc relationship within the plant as well as effecting the solubilities of compounds of zinc and phosphorus. It was also found that the addition of calcium carbonate decreased the amount of water-extractable zinc and phosphorus in sand culture. On the other hand, high phosphorus increased the amount of water-extractable zinc and this provided further evidence that the phosphorus-zinc interaction phenomenon was not in the soil external to the plant.

Paulsen and Rotini (43) concluded that the effect of applied phosphorus on the zinc concentration in the different parts of soybean plants appeared to originate in the roots and the phosphorus reduced the translocation of zinc to the upper parts of the plant.

Stukenholtz et al. (63) conducted investigations in the greenhouse and in the field to determine the mechanism of phosphorus-zinc interaction in the nutrition of corn. They concluded that the depressive action of phosphorus on zinc uptake of corn appeared to be largely physiological in nature. They stated explicitly that the phosphorus-zinc interaction occurred at the root surfaces and/or in the root cells of the corn plant and was not a chemical inactivation of zinc by phosphorus in the soil. The authors also found that the translocation of zinc from the roots to the tops was inhibited by an elevated phosphorus concentration and this resulted in a sharp reduction in the concentration of zinc of nodal and internodal tissues. No clearly defined phosphorus-zinc ratio was found above which yield restriction could be predicted. Corn appeared to tolerate high concentrations of phosphorus in its tissues providing a modest quantity of zinc was present.

Stukenholtz et al. (63) also reported that certain essential plant nutrient elements counteract the damaging effects of high amounts of soluble phosphorus in the soil. Their investigations indicated that nitrogen promotes zinc uptake at the same time that it benefits phosphorus utilization. High levels of indigenous or applied potassium reduce the depressive action of phosphorus on zinc.

Apparently, soil factors governing the concentration of zinc that is absorbed by plants are very complex. Undoubtedly, zinc deficiency in plants is likely to be aggravated or created by banded application of high rates of phosphorus or mixed fertilizer containing phosphorus. According to Langin et al. (70), zinc deficiency is greatest on soils that are calcareous and especially on those that are inherently high in phosphorus and low in soluble zinc. Langin et al. (70) stated that the more effectively the applied phosphorus is utilized by the crop, the more severe is the reduction in zinc uptake and utilization. These workers concluded that calcareous soils exhibiting a tendency of zinc deficiency perhaps should not be treated so as to afford maximum early uptake and utilization of applied phosphorus. They also concluded that low rates of phosphorus rather than large, infrequent applications would likely result in less damaging effect particularly from the standpoint of the uptake and utilization of zinc. Alternative to this procedure would be to apply zinc fertilizer whenever phosphorus is added to the soil, particularly when the level of zinc in the soil is considered to be low.

Langin et al. (70) reported that the damaging effect of phosphorus on zinc utilization was largely physiological in nature and was probably a plant root cell absorption phenomenon, and not an external zinc phosphate precipitation. They recognized, however, that root proliferation in the band of row-placed phosphorus may be a contributing factor due to inadequate exploration of a soil profile where enough soluble zinc may be present.

It has been reported that zinc deficient corn plants accumulate excessive amounts of iron (72). It has also been reported that rice plants growing on soils considered to be critically low in soluble zinc accumulate relatively a large amount of manganese, iron and sodium (52). Interference from the excessive accumulation of iron and other heavy metal cations may contribute to a physiological malfunction in zinc deficient corn or rice plants.

Yoshida and Tanaka (79) stated that under reductive conditions in submerged soils used for the production of rice, there may be two possibilities for the decreased solubility of soluble zinc. One of these is the formation of zinc sulfide whose solubility product is extremely low. Another is the adsorption or co-precipitation of zinc onto calcium carbonate particles in the presence of a large amount of carbon dioxide. The effect of flooding on the solubility of zinc and other micronutrient elements needs to be explored in more detail.

MATERIALS AND METHODS

The soil selected for these investigations conducted in the greenhouse was Crowley silt loam (Typic Albaqualfs) located at the Rice Experiment Station, a branch of the Louisiana Agricultural Experiment Station at Crowley. A 600 kilogram bulk sample of soil was collected from each of five different replications on the check plots of an experiment that was initially established in 1958 to determine the effects of different rates of phosphorus on the yield of rice (*Oryza sativa* L.) and S-1 white clover (*Trifolium repens* L.). The soil from the five replications was composited and thoroughly mixed. The soil was air-dried to approximately 17 per cent moisture, pulverized and passed through a 6 mm plastic screen. A representative sample was taken from the bulk sample for chemical analysis. The analytical methods used for determining the general fertility level and lime status of the soil are described in Louisiana State Agricultural Experiment Station Bulletin No. 632. The untreated soil contained 12 ppm of extractable phosphorus, 80 ppm of extractable potassium, 640 ppm of extractable magnesium. The pH of the soil was 5.3. The soil contained 1.3 ppm of dilute acid extractable zinc and 17.76 ppm of total zinc. The dilute acid extractable zinc content of the soil was determined by extracting the soil with 0.1 N HCl at a soil to solution ratio of 1:10. The total zinc content of the soil was determined with a mixture of concentrated nitric acid and perchloric acid after digesting the mixture on hot plate for approximately four hours. After filtering the acid-soil mixture through a Whatman No. 42 filter paper, dilute acid extractable zinc and total zinc was determined on suitable aliquots on a Perkin-Elmer Model 303 atomic absorption spectrophotometer. The soil contained 132 ppm of total phosphorus. Total phosphorus was determined by digesting a sample of soil in a mixture of concentrated nitric acid and perchloric acid. The concentration of phosphorus in the extract was measured colorimetrically on a Baush and Lomb spectronic 20 spectrophotometer by the vanadomolybdate method. The organic matter content of the soil was 0.65 per cent and was determined by wet digestion with chromic acid. The cation exchange capacity of the soil, determined with ammonium acetate adjusted to pH 7.0, was 9.02 me per 100 g of soil.

Exactly 2500 grams of soil on the oven-dried basis was placed into each of 208 three-liter capacity plastic-lined containers.

Three different investigations were conducted during a two-year period. The first investigation was conducted on Crowley silt loam with an initial pH of 5.3 to determine the effects of five rates of phosphorus and four rates of zinc on the production of dry matter of Oryza sativa L., cultivar Saturn, and on the composition of the plant tissue and the soil. The five rates of phosphorus and four rates of zinc were included in a complete factorial experiment with 20 treatment combinations. Four replications of each treatment combination were arranged in a complete randomized block design. The five rates of phosphorus were: 0, 50, 100, 200 and 400 ppm. Reagent grade monocalcium phosphate, $Ca(H_2PO_4)_2 \cdot H_2O$ containing 25 per cent P, served as the source of phosphorus. Calcium chloride was used to eliminate the variable amounts of calcium supplied by monocalcium phosphate treatments. The four rates of zinc were: 0, 1.8, 3.6 and 7.2 ppm. Fertilizer grade zinc sulphate, $ZnSO_4 \cdot H_2O$, containing 36% Zn, was used as the source of zinc. Variable amounts of sulphate sulphur applied by the zinc sulphate treatments were eliminated through addition of different amounts of reagent grade sodium sulphate. Soil in each of the 80 containers received a preplant application of nitrogen and potassium at rates equivalent to 50 ppm N and 50 ppm K. Urea and muriate of potash served as the source of nitrogen and potassium, respectively. All preplant fertilizers were thoroughly incorporated in the soil in each container by mixing. Immediately before planting 16 rice seeds in the soil in each container, the moisture content was adjusted to approximately 20 per cent. After the rice seeds germinated, the soil was maintained at 20 per cent moisture for a two-week period. The soil in each container was flooded 14 days after germination with approximately 2 cm of distilled and deionized water. The rice seedlings were thinned to eight plants per container at 16 days after germination. Twenty-eight days after germination, the depth of water was increased to a total of 4 cm and this depth was maintained during the 125 days duration of the experiment. Thirty-five days after germination, the rice plants were top-dressed with urea dissolved in water at a rate equivalent to 50 ppm N and the plants were sprayed with a water solution containing formamidine to control spider mites. A second application of formamidine was made 42 days after germination of the rice seeds. The rice plants were top-dressed with an aqueous solution containing potassium chloride at a rate equivalent to 50 ppm K 56 days after germination.

At the active vegetative phase of development which occurred 61 days after germination, four of the eight rice plants were harvested. The rice plants were cut immediately above soil level and placed in cloth bags for drying. The plant tissue was dried in a forced draft oven for 24 hours at 70^{o}C. After drying, the plant material was weighed, the dry matter was recorded, and the plant material was divided into stem and leaves and ground in a stainless steel Wiley mill to pass a 20 mm sieve. The ground plant material was stored in 125 ml screw-top glass containers for chemical analysis.

At the reproductive phase of development which occurred 88 days after germination, three plants were harvested. The plants were cut immediately above ground level, placed in cloth bags and dried in a forced draft oven at 70°C for 24 hours. The plant material was weighed and recorded and then ground in a stainless steel Wiley mill to pass a 20 mm sieve and stored in 125 ml screw-top glass containers for chemical analysis.

At the ripening phase of development which occurred 125 days after germination, the one remaining rice plant was harvested. The plant was cut immediately above soil level, placed into cloth bags and dried in a forced draft oven at 70°C for 24 hours. The plant material was weighed and recorded. Plant material was then ground in a stainless steel Wiley mill to pass a 20 mm sieve and stored in 125 ml screw-top glass containers for chemical analysis.

After the final harvest, the soil in each of the containers was allowed to air dry for 7 days and the root of the rice plants were carefully removed and thoroughly washed six times by submergence and agitation in distilled water. After drying, the rice roots were weighed, ground and stored in screw-top glass containers for chemical analysis.

The concentration of phosphorus, zinc, calcium, magnesium and iron was determined in the plant tissue collected from each container. The plant material was digested in a mixture of concentrated nitric acid and perchloric acid by heating on a hot plate. The residue resulting from the digestion was filtered through Whatman No. 2 filter paper to remove silica. After the filtrate was brought up to a volume of a 100 ml, suitable aliquot was taken for the chemical analysis. Phosphorus was determined colorimetrically on the Baush & Lomb spectronic 20 spectrophotometer. Zinc, calcium, magnesium and iron were determined on the Perkin & Elmer Model 303 atomic absorption spectrophotometer.

The soil in each container was sampled for chemical analysis. Chemical analysis of the soil included determinations for extractable phosphorus, zinc, calcium, magnesium and potassium.

The second investigation was conducted on Crowley silt loam adjusted to pH 6.3 with calcium carbonate to determine the effects of five rates of phosphorus and four rates of zinc on the production of dry matter of *Oryza sativa* L., cultivar Saturn and on the chemical composition of the plant tissue and soil.

A laboratory method involving the addition of increments of calcium hydroxide to samples of the soil was used to estimate the amount of lime that would be needed to increase the soil reaction of Crowley silt loam from pH 5.3 to pH 6.3. Reagent grade calcium carbonate was added at a rate equivalent to 3.36 metric tons per hectare (1.5 tons per acre) to the soil in each container. The liming amendment was thoroughly incorporated into the soil by mixing and was allowed to equilibrate 72 hours before seeding rice.

The chemical treatments, production practices and method of harvesting the plant tissue and soil samples employed in the second investigation were identical with those used in the first investigation.

A third and final investigation was conducted on the Crowley silt loam soil, pH 5.3, to evaluate the effects of five sources of phosphorus with and without supplementary zinc on the production of dry matter of Oryza sativa L., cultivar Saturn and on the chemical composition of rice plant and soil.

The five sources of phosphorus used were: normal superphosphate (NSP), 8.95% P, concentrated superphosphate (CSP), 20.24% P, monoammonium phosphate (MAP), 27.82% P, diammonium phosphate (DAP), 23.32% P, and ammonium polyphosphate(APP), 27.28% P. A check treatment was used in which no phosphorus was applied. All of the sources of phosphorus were applied at a rate equivalent to 50 ppm P. Zinc sulphate monohydrate containing 36% Zn was used as the source of zinc. The zinc sulphate was applied at a rate equivalent to 3.6 ppm of elemental zinc. Nitrogen supplied in Urea was used on the soil that received no phosphorus and on soils that received the five sources of phosphorus at rates so that the final content of preplant nitrogen was 50 ppm. A uniform application of potassium chloride was added at a rate of 50 ppm of potassium. All of the preplant fertilizers were thoroughly mixed with the soil.

The six phosphorus treatments, including five phosphorus sources and a no phosphorus treatment, combined with the two zinc treatments were included in a split plot design with 12 treatment combinations. Four replications of each of the treatment combination were used. All treatment combinations were completely randomized.

Sixteen seed of Saturn rice were planted in each container after the moisture content of the soil was adjusted to approximately 20 per cent. The soil was flooded to a depth of 2 cm with distilled water 14 days after the rice seeds emerged. The rice plants were thinned to eight plants per container 16 days after emergence. The depth of the flooded water was increased to 4 cm 28 days after emergence. Rice plants were harvested 63 days after germination and they were placed in cloth bags and dried in a forced draft oven at 70°C for 24 hours. After drying, the plants were weighed and the weights were recorded. The entire rice plant was ground in a stainless steel Wiley mill to pass a 20 mm sieve. The plant tissue was stored in 125 ml capacity glass containers for chemical analysis. The concentration of phosphorus, zinc, calcium, magnesium and iron was determined in the plant tissue collected from each container. The plant material was digested in a mixture of concentrated nitric acid and perchloric acid by heating on a hot plate. The residue resulting from the digestion was filtered through Whatman No. 42 filter paper to remove silica. After the filtrate was brought up to a volume of a 100 ml, suitable aliquot was taken for the chemical analysis. Phosphorus was determined colorimetrically on the Baush & Lomb spectronic 20 spectrophotometer. Zinc, calcium, magnesium and iron were determined on the Perkin & Elmer Model 303 atomic absorption spectrophotometer.

Soil samples were collected from each of the 48 containers and were allowed to air dry prior to chemical analysis. Chemical analysis of the soil included determinations for extractable phosphorus, zinc, calcium, magnesium and potassium.

All of the yield data and chemical analysis of the plant tissue and soils were statistically analyzed by the methods described by Steel and Torrie (60). An analysis of variance was calculated for the two factorial experiments and for the split plot experiment. The "F" test was employed to determine significance among treatments. The "t" test was employed to determine which treatments were significantly different.

RESULTS AND DISCUSSION

The effects of applications of phosphorus and zinc on the production of dry matter, the concentration of phosphorus and zinc, the uptake of phosphorus and zinc, the ratio of the concentration of phosphorus and zinc and the ratio of the uptake of phosphorus and zinc by *Oryza sativa* L., cultivar Saturn, at three phases of growth and development on unlimed Crowley silt loam, pH 5.3, are presented in Tables 1, 2, 3, 4, 5, 6 and 7.

The effects of applications of phosphorus and zinc on the production of dry matter of *Oryza sativa* L., cultivar Saturn, at three phases of growth and development on unlimed Crowley silt loam, pH 5.3, are presented in Table 1 and in Figures 1, 2, 3 and 4. The data indicate that the addition of 50, 100, 200 and 400 ppm of phosphorus resulted in a significant increase over the check in the production of dry matter of *Oryza sativa* L. at the vegetative, reproductive and ripening phases of growth and development. The addition of the first increment of 50 ppm of phosphorus resulted in a large significant increase in yield at each of the three growth and development phases and in the total yield. Application of additional increments of phosphorus above the 50 ppm rate did not result in a further increase in the production of dry matter of rice at the vegetative and reproductive phases. A slight but non significant increase in the total production of dry matter was obtained when the rate of phosphorus was increased from 50 ppm

Table 1 .-The effects of applications of phosphorus and zinc on the production of dry matter of <u>Oryza sativa</u> L., cultivar Saturn, at three phases of growth and development on unlimed Crowley silt loam[1/], pH 5.3.

Treatments		Growth and development phases			
P	Zn	Vegetative[2/]	Reproductive[3/]	Ripening[4/]	Total
ppm		Dry matter, g/pot, av. of 4 reps.			
0	0	1.18	1.34	1.29	3.81
0	1.8	1.56	.86	.75	3.17
0	3.6	2.03	1.00	1.21	4.24
0	7.2	1.66	1.34	1.05	4.05
50	0	12.36	7.49	11.06	30.91
50	1.8	13.20	9.06	8.11	30.37
50	3.6	11.60	10.16	9.63	31.39
50	7.2	12.56	9.15	10.84	32.55
100	0	13.59	8.73	9.68	32.00
100	1.8	13.79	9.21	8.25	31.25
100	3.6	12.52	9.85	10.84	33.21
100	7.2	13.63	10.25	10.84	34.72
200	0	12.93	10.53	9.83	33.29
200	1.8	11.28	9.35	10.04	30.67
200	3.6	14.31	9.21	8.90	32.42
200	7.2	13.69	8.80	9.45	31.94
400	0	12.13	9.41	10.05	31.59
400	1.8	13.21	8.75	9.31	31.27
400	3.6	12.83	9.61	9.95	32.39
400	7.2	15.11	9.48	9.64	34.23
LSD, 5%		2.23	1.50	1.60	2.90

1/The untreated soil contained 12 ppm of extractable phosphorus and 1.3 ppm of extractable zinc.
2/Four plants were harvested 61 days after planting.
3/Three plants were harvested 88 days after planting.
4/One plant was harvested 125 days after planting.

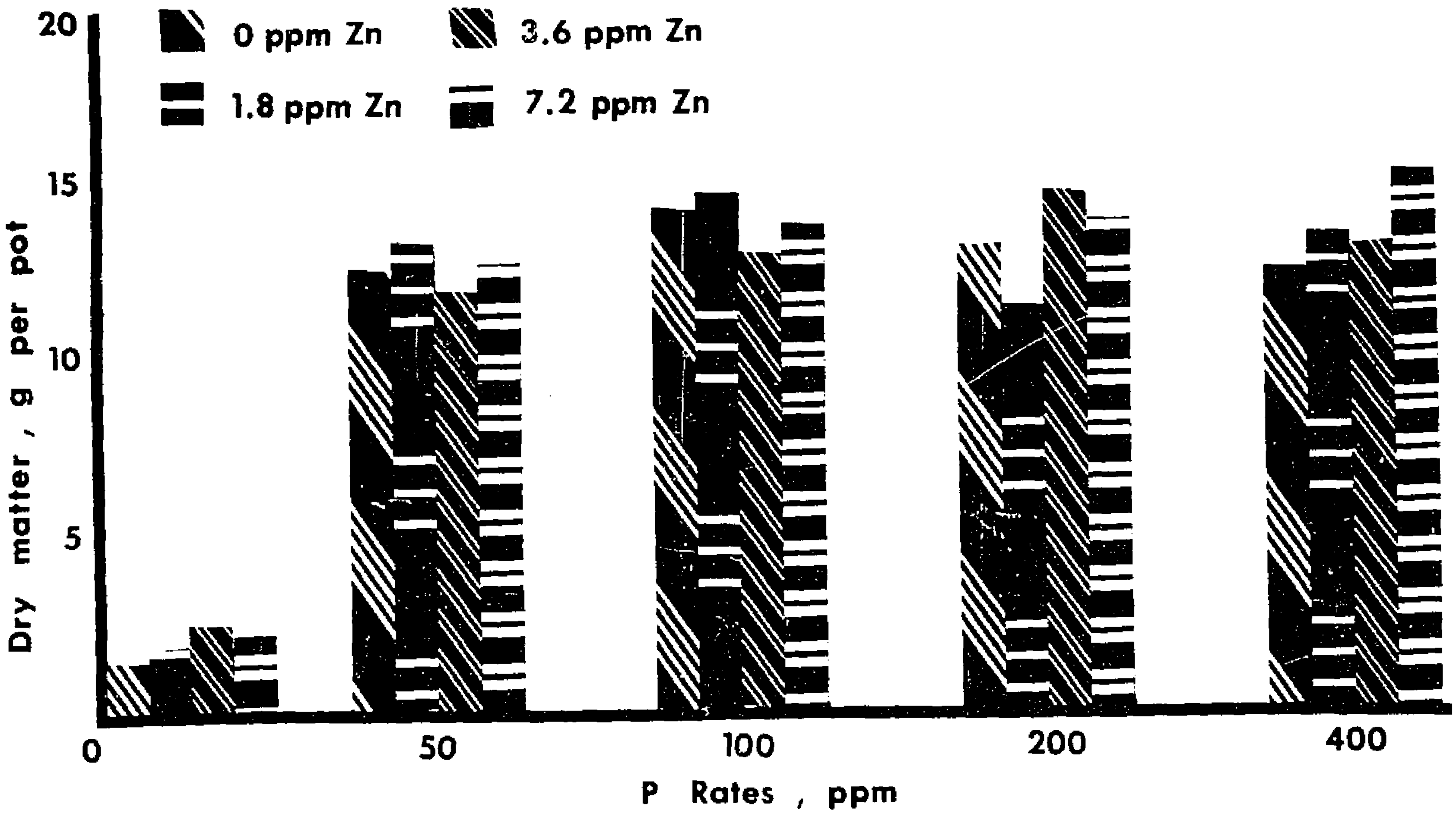

Fig. 1.- The effects of applications of phosphorus and zinc on the production of dry matter of *Oryza sativa* L., cultivar Saturn, at the vegetative phase of growth and development on unlimed Crowley silt loam, pH 5.3.

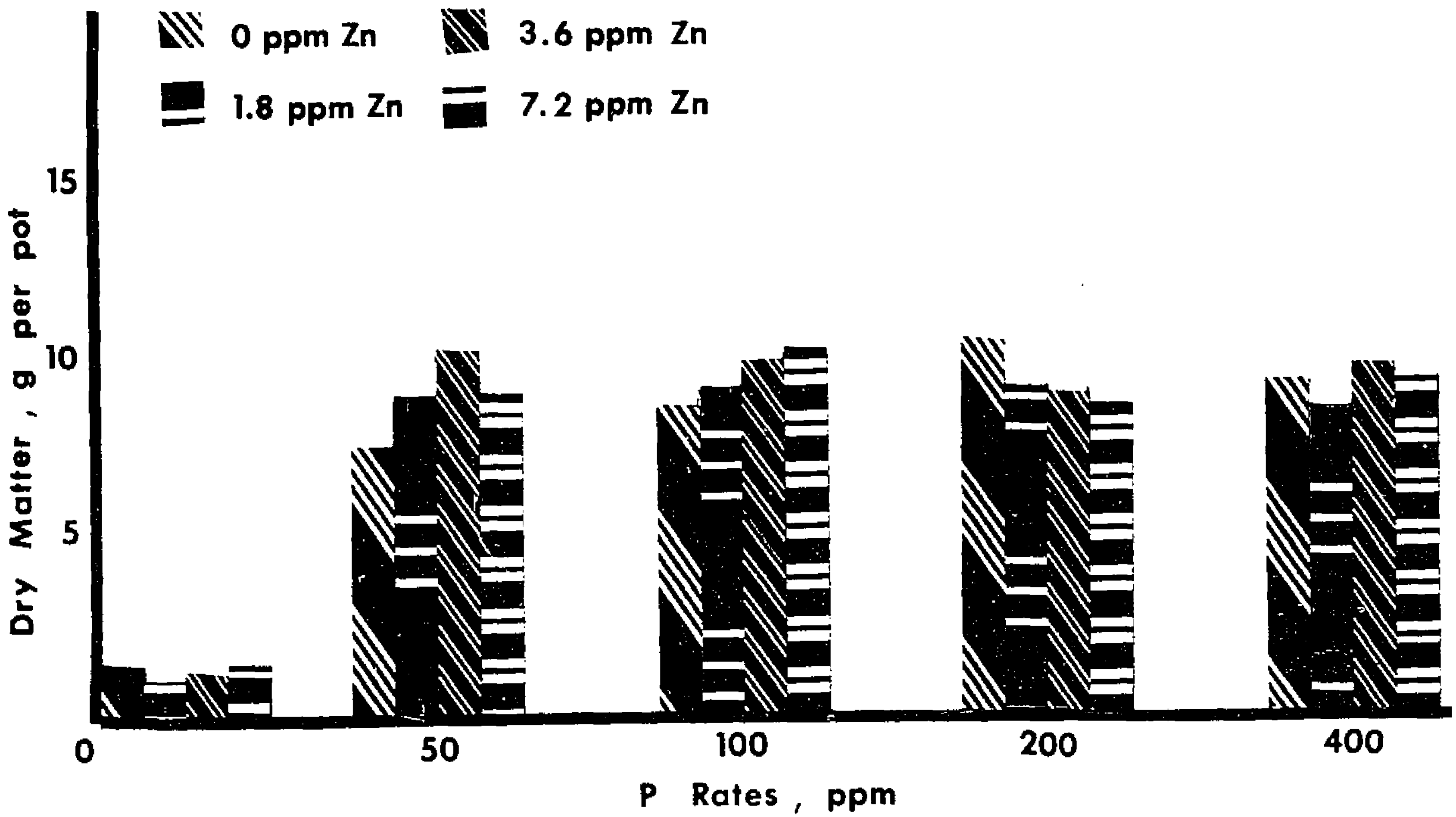

Fig. 2.- The effects of applications of phosphorus and zinc on the production of dry matter of Oryza sativa L., cultivar Saturn, at the reproductive phase of growth and development on unlimed Crowley silt loam, pH 5.3.

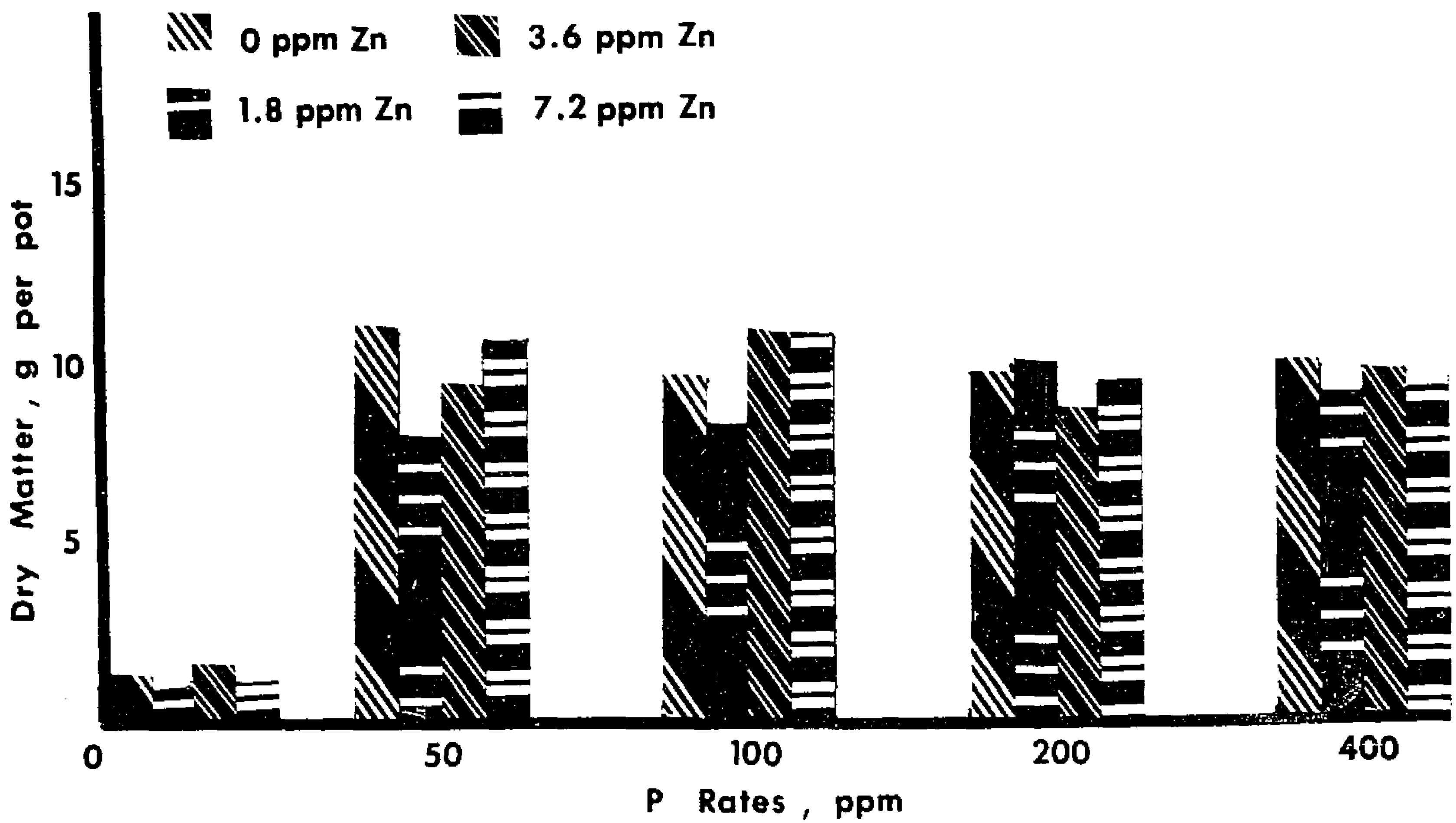

Fig. 3.- The effects of applications of phosphorus and zinc on the production of dry matter of *Oryza sativa* L., cultivar Saturn, at the ripening phase of growth and development on unlimed Crowley silt loam, pH 5.3.

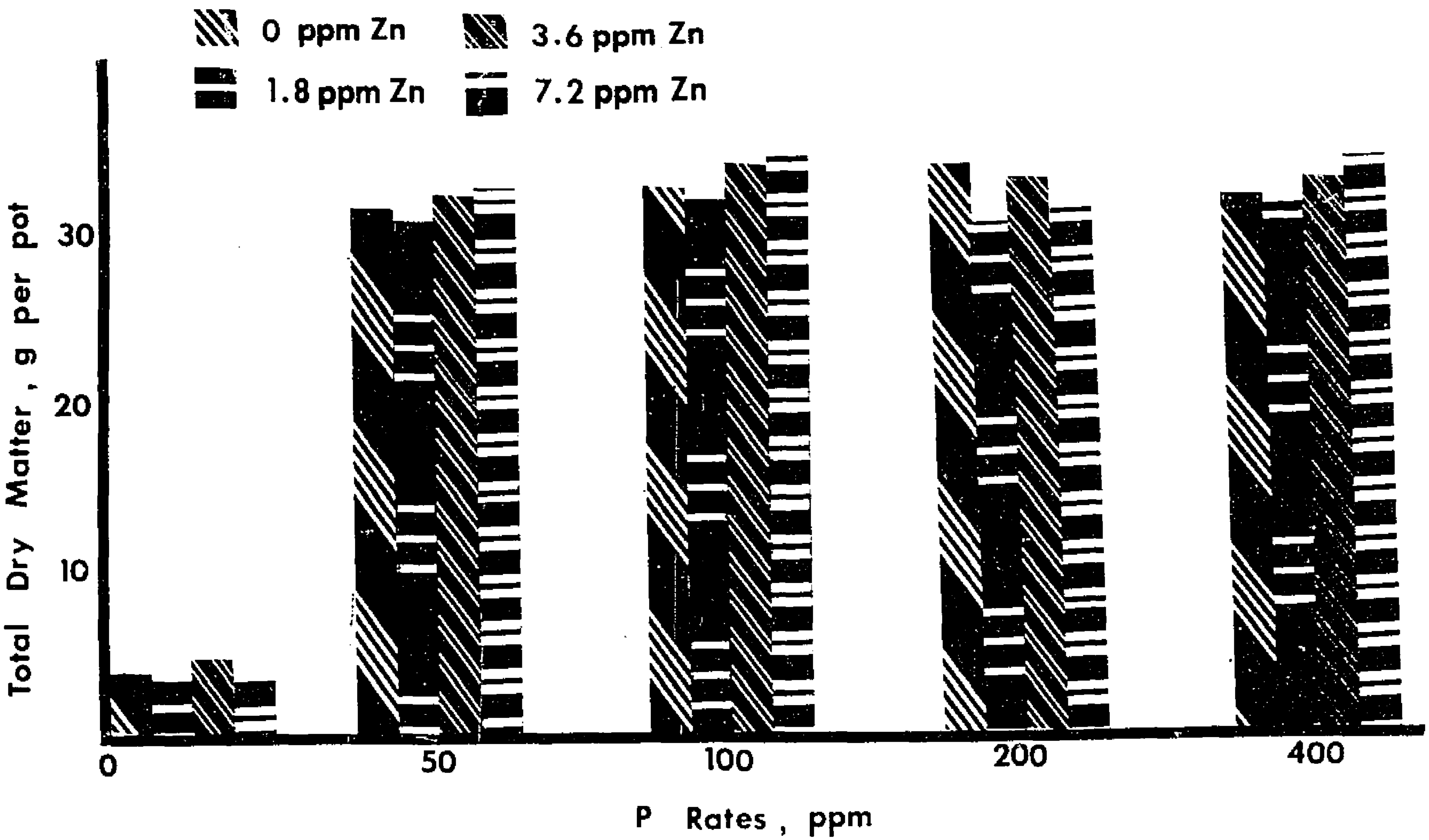

Fig. 4.- The effects of applications of phosphorus and zinc on the total production of dry matter of Oryza sativa L., cultivar Saturn, at three phases of growth and development on unlimed Crowley silt loam, pH 5.3.

to 100 ppm on the unlimed Crowley silt loam soil.

The application of zinc sulphate at rates equivalent to 1.8, 3.6 and 7.2 ppm of elemental zinc to soil that did not receive phosphorus had no measurable effect on the production of dry matter of rice plants at the vegetative, reproductive and ripening phases of growth and development. The unlimed Crowley silt loam soil contained 12 ppm of extractable phosphorus and 1.3 ppm of extractable zinc. The data suggest that the phosphorus concentration in the soil was critically low and the zinc content was apparently adequate on soils that did not receive phosphorus as well as on soils that received relatively large amounts of supplementary phosphorus. Apparently 1.3 ppm of extractable zinc in Crowley silt loam at pH 5.3 was adequate for rice grown on the submerged soil that contained either a low or high level of phosphorus.

A statistically significant interaction between phosphorus and zinc did not occur in rice at the vegetative and reproductive phases or in total yield. A significant interaction was calculated between phosphorus and zinc when the rice plants approached maturity. Despite the significant interaction between levels of phosphorus and zinc, there was no evidence that application of zinc had any important effect on response to phosphorus. Likewise, the data indicate that the higher rates of phosphorus had no consistantly depressing effect on zinc.

The effects of applications of phosphorus and zinc on the concentration of phosphorus in plant tissue of _Oryza sativa_ L., cultivar Saturn, grown on unlimed Crowley silt loam, pH 5.3, at three growth and development phases are presented in Table 2. The application of phosphorus at the rates of 50, 100, 200 and 400 ppm resulted in a significant increase over the check in the concentration of phosphorus in the plant tissue. The concentration of phosphorus in the rice tissue of plants grown on the Crowley silt loam that did not receive an application of phosphorus varied from 125 ppm to 473 ppm at the three growth and development phases. According to Chapman (20) , rice tissue that contain less than 1000 ppm of phosphorus is considered to be critically low in phosphorus. With the exception of the concentration of phosphorus in the rice tissue at ripening phase of growth and development, the application of 50 ppm of phosphorus resulted in a phosphorus content of the tissue well above the established critical level of 1000 ppm. Further addition of phosphorus above the 50 ppm rate apparently resulted in a luxurious uptake of phosphorus from the soil with no measurable effect on yield. The application of 1.8, 3.6 and 7.2 ppm of zinc to the Crowley soil had no significant effect on the concentration of phosphorus in the tissue of the rice plants.

The effects of applications of phosphorus and zinc on the concentration of zinc in plant tissue of _Oryza sativa_ L., cultivar Saturn, grown on unlimed Crowley silt loam, pH 5.3, at three growth and development phases are presented in Table 3.

Table 2.-The effects of applications of phosphorus and zinc on the concentration of phosphorus in plant tissue of *Oryza sativa* L., cultivar Saturn, grown on unlimed Crowley silt loam[1], pH 5.3, at three growth and development phases.

Treatments		Growth and development phases		
P	Zn	Vegetative[2]	Reproductive[3]	Ripening[4]
ppm			P, ppm	
0	0	473	350	144
0	1.8	392	170	125
0	3.6	416	222	155
0	7.2	370	313	235
50	0	1509	1005	791
50	1.8	1584	973	816
50	3.6	1637	1039	879
50	7.2	1652	1167	975
100	0	1739	1277	1062
100	1.8	1702	1224	1094
100	3.6	1712	1245	1078
100	7.2	1703	1216	1140
200	0	1500	1289	1096
200	1.8	1501	1364	1152
200	3.6	1906	1328	1125
200	7.2	1941	1316	1152
400	0	2322	1354	1176
400	1.8	2330	1346	1196
400	3.6	2370	1355	1213
400	7.2	2051	1407	1259
LSD, 5%		76	81	65

[1]The untreated soil contained 12 ppm of extractable phosphorus and 1.3 ppm of extractable zinc.

[2]Four plants were harvested 61 days after planting.

[3]Three plants were harvested 88 days after planting.

[4]One plant was harvested 125 days after planting.

Table 3 .-The effects of applications of phosphorus and zinc on the concentration of zinc in plant tissue of Oryza sativa L., cultivar Saturn, grown on unlimed Crowley silt loam1/, pH 5.3, at three growth and development phases.

Treatments		Growth and development phases		
P	Zn	Vegetative2/	Reproductive3/	Ripening4/
ppm			Zn, ppm	
0	0	43	20	56
0	1.8	42	32	55
0	3.6	41	35	71
0	7.2	75	42	84
50	0	23	35	59
50	1.8	37	35	64
50	3.6	38	41	81
50	7.2	45	45	72
100	0	27	34	60
100	1.8	34	37	64
100	3.6	33	31	70
100	7.2	40	41	94
200	0	22	28	60
200	1.8	27	37	59
200	3.6	30	35	69
200	7.2	36	39	81
400	0	25	26	52
400	1.8	26	34	59
400	3.6	28	30	61
400	7.2	22	32	61
LSD, 5%		13	11	16

1/ The untreated soil contained 12 ppm of extractable phosphorus and 1.3 ppm of extractable zinc.
2/ Four plants were harvested 61 days after planting.
3/ Three plants were harvested 88 days after planting.
4/ One plant was harvested 125 days after planting.

The application of zinc at the rates of 1.8, 3.6 and 7.2 ppm did not result in a consistant increase in the concentration of zinc in plant tissue. In general, the application of 7.2 ppm of zinc resulted in the largest concentration of zinc in the tissue. The data suggest that the application of 400 ppm of phosphorus resulted in a slight but non-significant depression in the concentration of zinc in the rice plant.

The data in Table 4 and in Figures 5, 6 and 7 show the effects of applications of phosphorus and zinc to unlimed Crowley silt loam, pH 5.3, on the uptake of phosphorus by Oryza sativa L., cultivar Saturn, at three growth and development phases. Rice plants at the vegetative phase of development absorbed more phosphorus from the soil at each level of phosphorus and zinc than did the plants at the reproductive and ripening phases. The application of 50 ppm of phosphorus resulted in a large significant increase in the uptake of phosphorus by rice plants at each of the growth and development phases. Progressive increases in the uptake of phosphorus at all growth phases were noted at each rate of applied phosphorus. The highest uptake of phosphorus by rice plants at each growth phase occurred when 400 ppm of phosphorus was added to the unlimed Crowley silt loam soil. The application of the different rates of zinc had no significant effect on the uptake of phosphorus by the rice plants at any growth phase. The data indicate that the application of zinc did not induce a phosphorus

Table 4.- The effects of applications of phosphorus and zinc to unlimed Crowley silt loam1/, pH 5.3, on the uptake of phosphorus by *Oryza sativa* L., cultivar Saturn, at three growth and development phases.

Treatments		Growth and development phases		
P	Zn	Vegetative2/	Reproductive3/	Ripening4/
ppm		P, mgm per pot		
0	0	0.56	0.47	0.19
0	1.8	0.61	0.15	0.09
0	3.6	0.85	0.22	0.19
0	7.2	0.61	0.42	0.25
50	0	18.66	7.53	8.75
50	1.8	20.92	8.82	6.62
50	3.6	18.99	10.56	8.47
50	7.2	20.76	10.68	10.57
100	0	23.64	11.15	10.29
100	1.8	23.47	11.28	9.02
100	3.6	21.44	12.27	11.69
100	7.2	23.22	12.46	12.36
200	0	19.40	13.58	10.77
200	1.8	16.94	12.75	11.57
200	3.6	27.28	12.24	10.01
200	7.2	26.57	11.58	10.89
400	0	28.17	12.75	11.82
400	1.8	30.79	11.78	11.13
400	3.6	30.41	13.02	12.07
400	7.2	30.99	13.34	12.14
LSD, 5%		2.20	1.50	1.30

1/ The untreated soil contained 12 ppm of extractable phosphorus and 1.3 ppm of extractable zinc.
2/ Four plants were harvested 61 days after planting.
3/ Three plants were harvested 88 days after planting.
4/ One plant was harvested 125 days after planting.

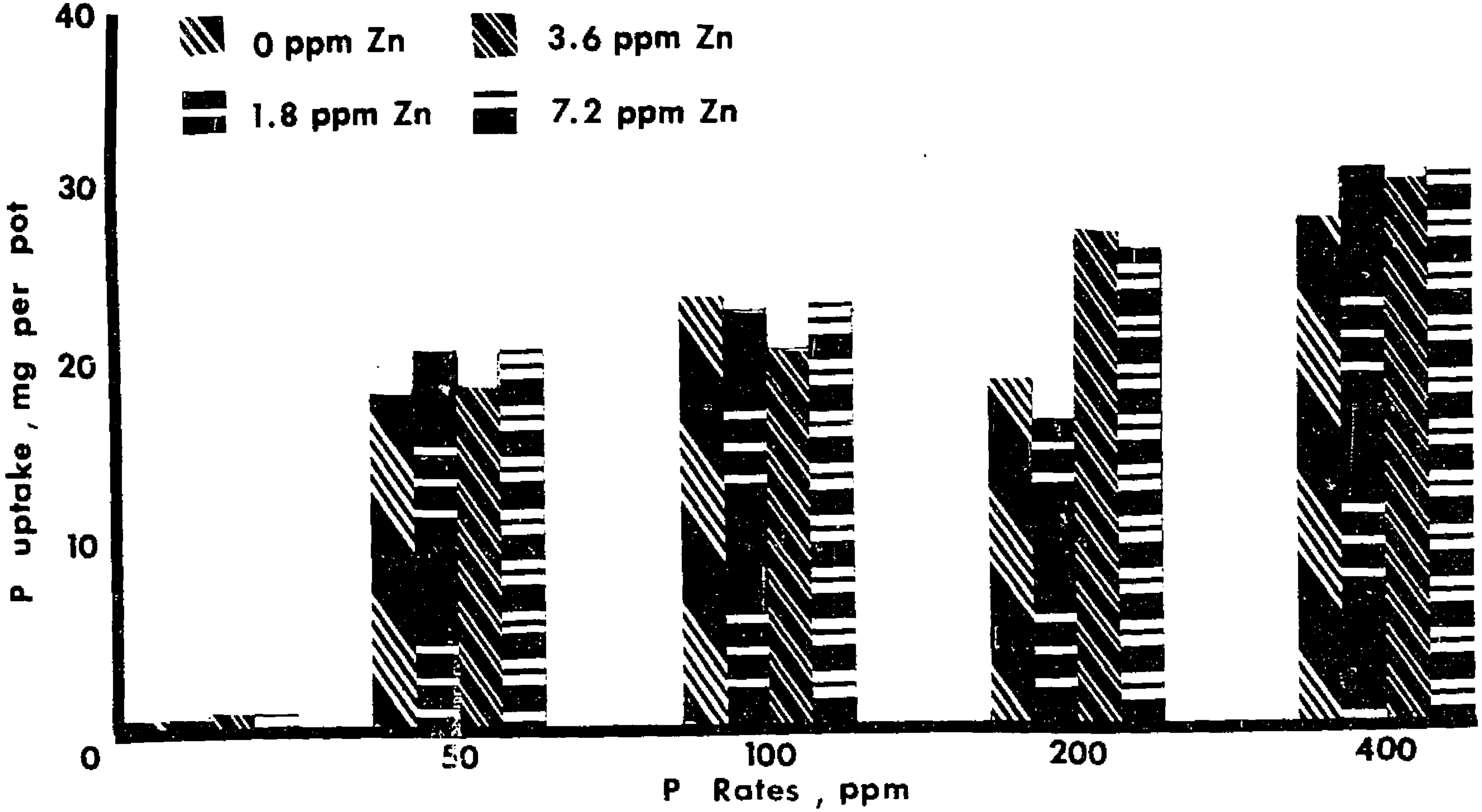

Fig.5.- The effects of applications of phosphorus and zinc to unlimed Crowley silt loam, pH 5.3, on the uptake of phosphorus by <u>Oryza sativa</u> L., cultivar Saturn. at the vegetative phase of growth and development.

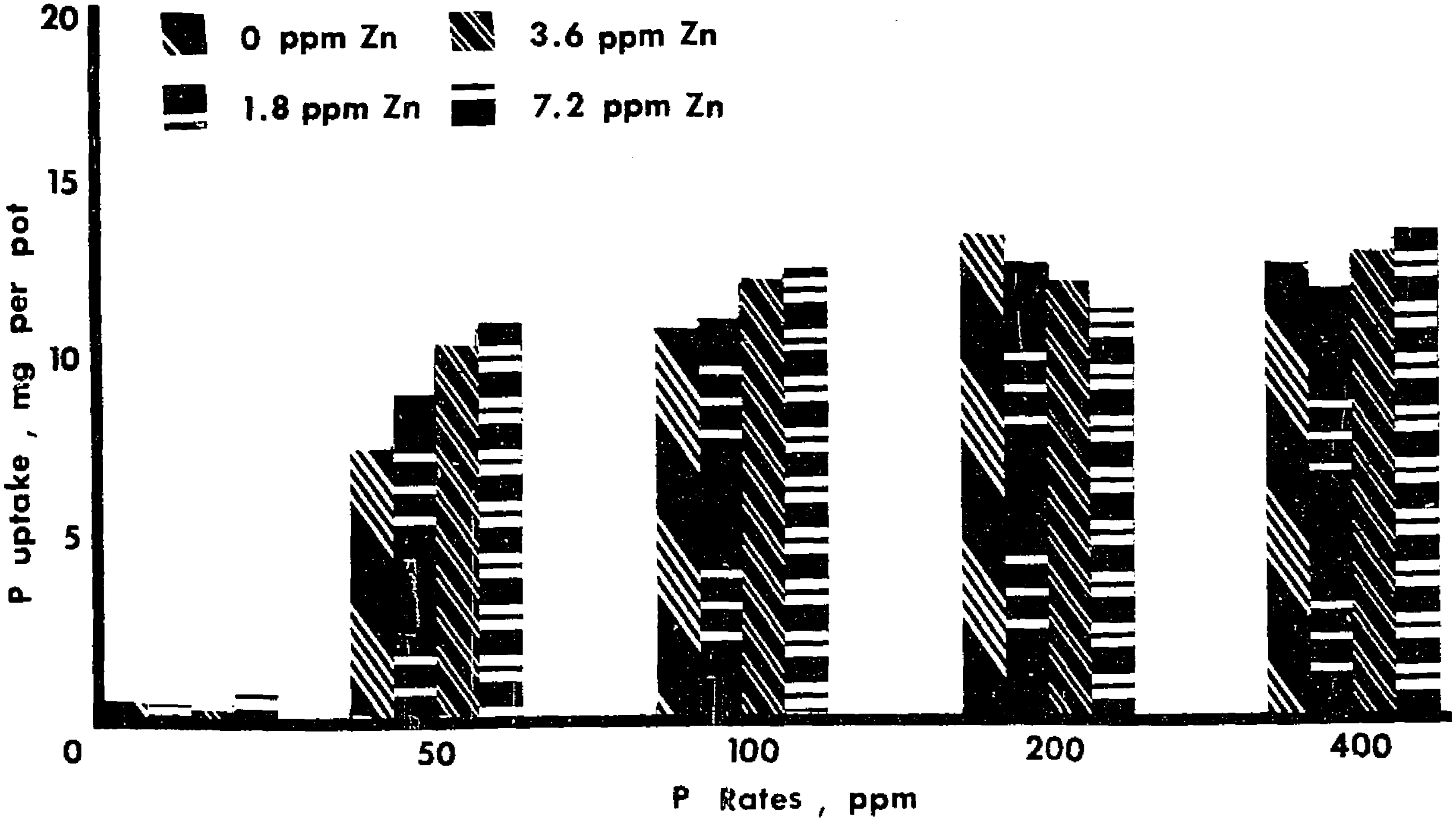

Fig. 6.- The effects of applications of phosphorus and zinc to unlimed Crowley silt loam, pH 5.3, on the uptake of phosphorus by *Oryza sativa* L., cultivar Saturn, at the reproductive phase of growth and development.

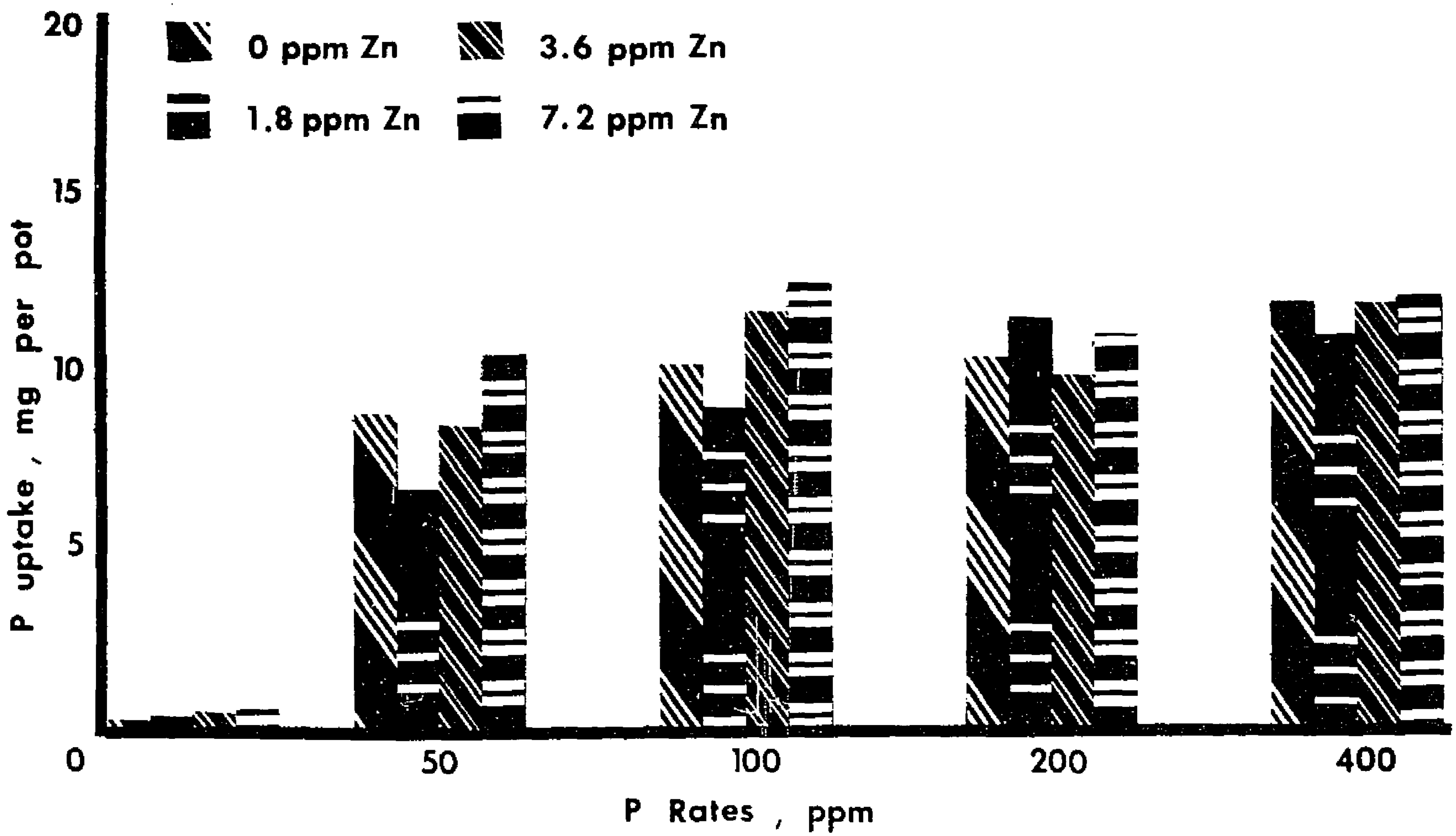

Fig. 7.- The effects of applications of phosphorus and zinc to unlimed Crowley silt loam, pH 5.3, on the uptake of phosphorus by *Oryza sativa* L., cultivar Saturn, at the ripening phase of growth and development.

deficiency even though the soil contained only 12 ppm of extractable phosphorus. The dilute acid extractable zinc content of the unlimed Crowley silt loam was 1.3 ppm. A significant response to application of zinc measured by the production of dry matter was not obtained in this investigation. This data was in agreement with those obtained by Sedberry et al. (52) in which yield response by rice grown on prairie soils in Louisiana had been obtained following application of zinc when the zinc content of the soil was less than 1.2 ppm. There was no statistically significant interaction between phosphorus and zinc on the uptake of phosphorus by rice plants at the three different phases of growth and development of rice plants. This further substantiates that the application of zinc had no measurable effect on the uptake of phosphorus by rice plants.

The effects of applications of phosphorus and zinc to unlimed Crowley silt loam, pH 5.3, on the uptake of zinc by *Oryza sativa* L., cultivar Saturn, at three growth and development phases are presented in Table 5 and in Figures 8, 9 and 10. The data indicate that when phosphorus was not added, the application of each rate of zinc resulted in a progressive but non-significant increase in the uptake of zinc at each growth phase. The application of 7.2 ppm of zinc to the soil that did not receive phosphorus resulted in a large significant increase over the check in zinc uptake of rice plants at the vegetative phase. The application of each rate of zinc to the soil that received

Table 5 .-The effects of applications of phosphorus and zinc to unlimed Crowley silt loam[1/], pH 5.3, on the uptake of zinc by *Oryza sativa* L., cultivar Saturn, at three growth and development phases.

Treatments		Growth and development phases		
P	Zn	Vegetative[2/]	Reproductive[3/]	Ripening[4/]
ppm		Zn , μg per pot		
0	0	51	27	73
0	1.8	65	28	42
0	3.6	83	35	86
0	7.2	125	57	88
50	0	284	269	652
50	1.8	486	320	523
50	3.6	437	414	779
50	7.2	566	413	783
100	0	361	327	582
100	1.8	465	340	531
100	3.6	409	310	764
100	7.2	540	419	1022
200	0	290	298	586
200	1.8	299	350	589
200	3.6	434	325	611
200	7.2	488	344	762
400	0	306	246	524
400	1.8	338	294	553
400	3.6	362	287	604
400	7.2	329	304	591
LSD, 5%		57	45	36

1/ The untreated soil contained 12 ppm of extractable phosphorus and 1.3 ppm of extractable zinc.
2/ Four plants were harvested 61 days after planting.
3/ Three plants were harvested 88 days after planting.
4/ One plant was harvested 125 days after planting.

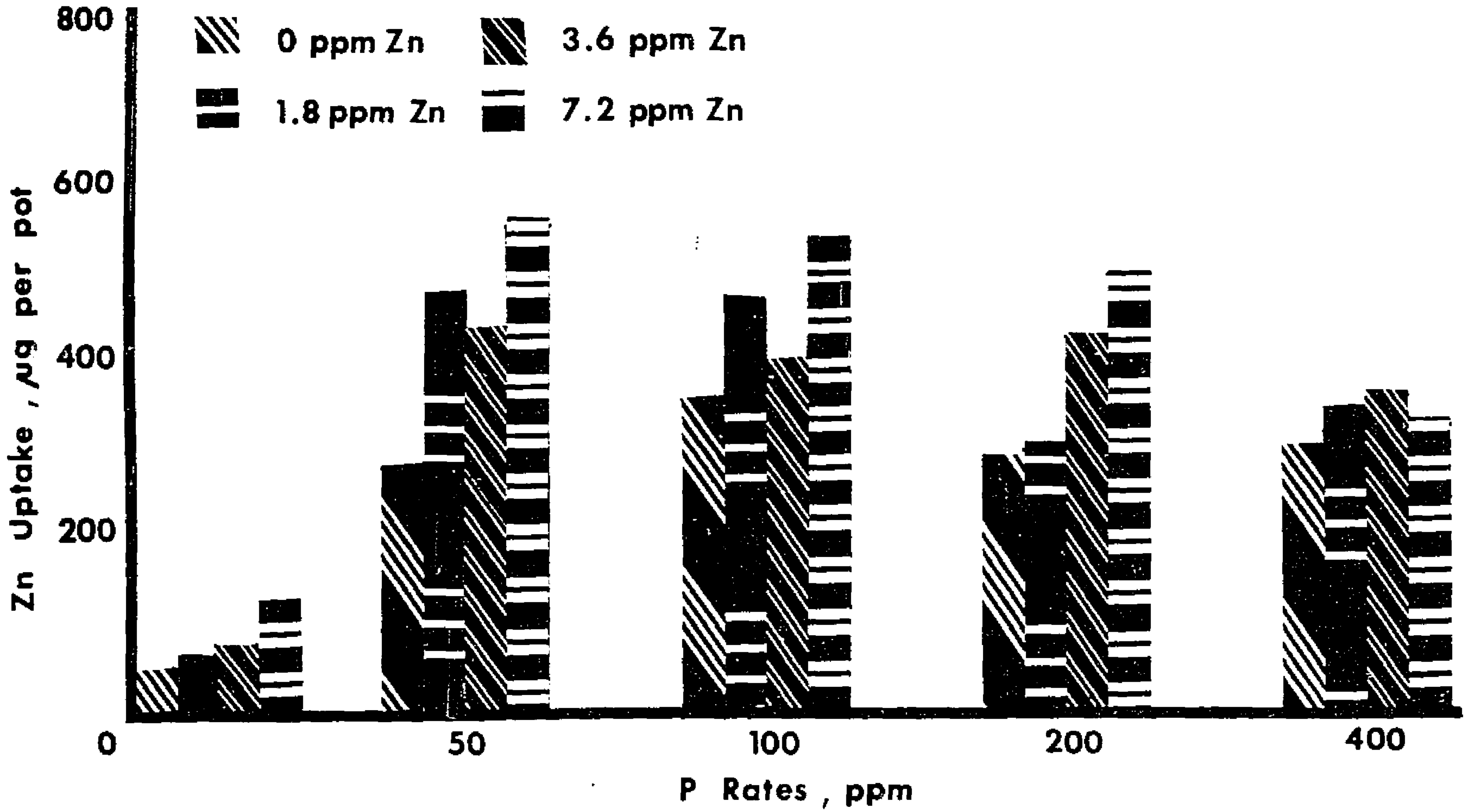

Fig. 8.- The effects of applications of phosphorus and zinc to unlimed Crowley silt loam, pH 5.3, on the uptake of zinc by *Oryza sativa* L., cultivar Saturn, at the vegetative phase of growth and development.

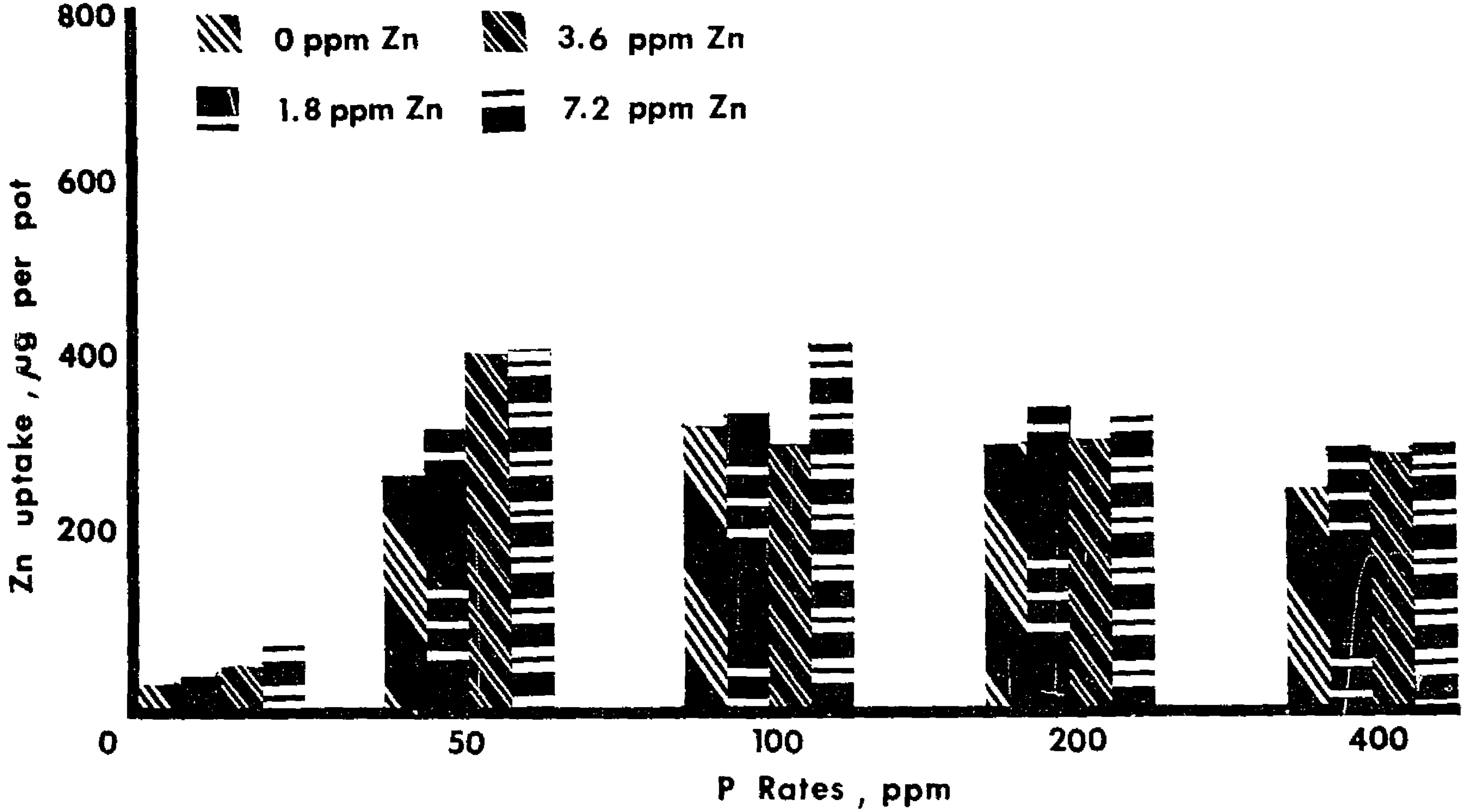

Fig. 9.- The effects of applications of phosphorus and zinc to unlimed Crowley silt loam, pH 5.3, on the uptake of zinc by <u>Oryza sativa</u> L., cultivar Saturn, at the reproductive phase of growth and development.

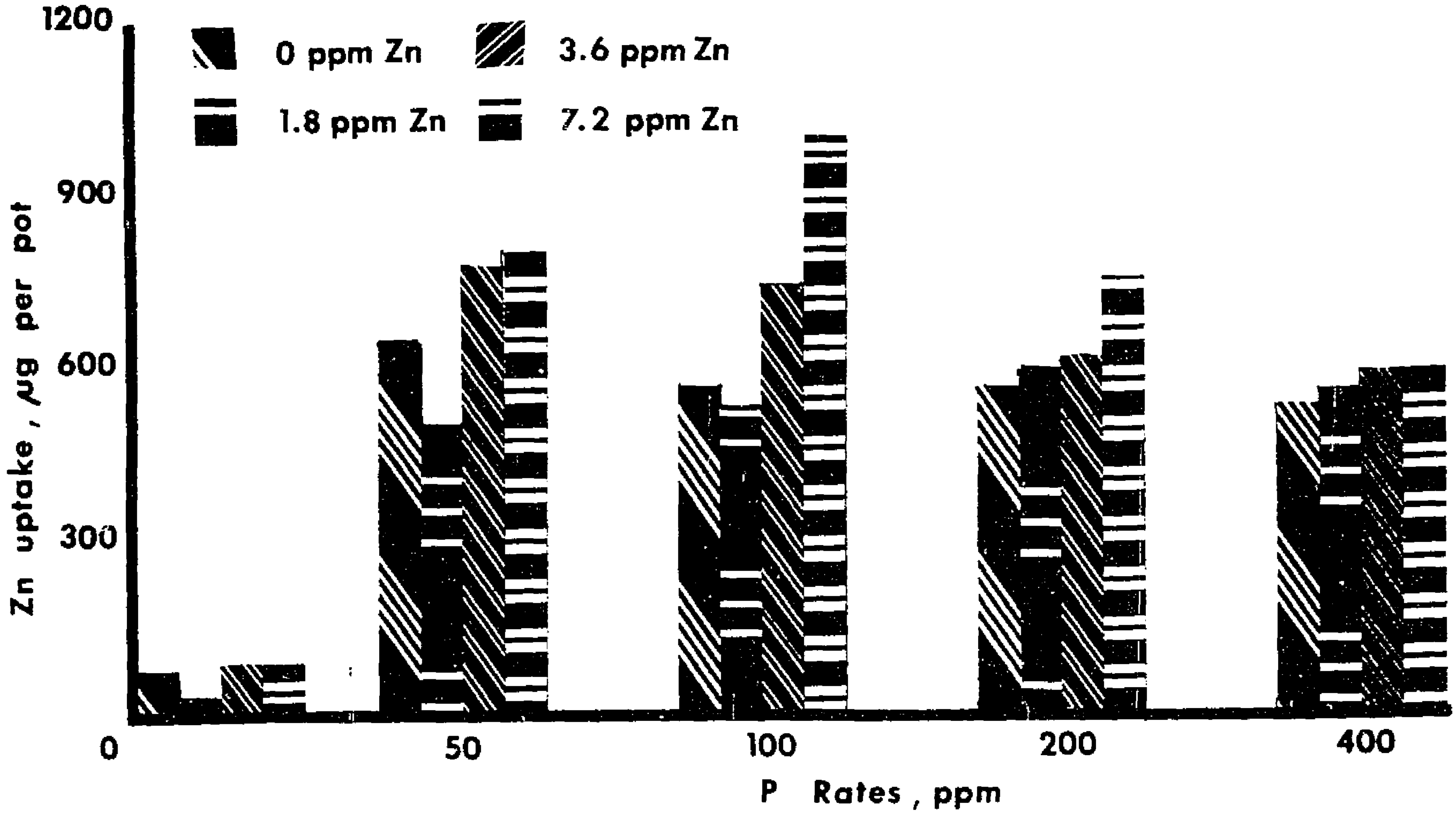

Fig. 10.- The effects of applications of phosphorus and zinc to unlimed Crowley silt loam, pH 5.3, on the uptake of zinc by Oryza sativa L., cultivar Saturn, at the ripening phase of growth and development.

50 ppm of phosphorus resulted in significant increases in the zinc uptake over the soil that did not receive zinc at the vegetative and reproductive phases of rice plants. The data in Table 5 do not indicate that the application of the five rates of phosphorus reduced the uptake of indigenous or applied zinc. The statistical analysis indicated that there was no significant interaction between the phosphorus and zinc rates and the uptake of zinc by rice at the vegetative, reproductive and ripening phases of growth and development of the rice plants.

The effects of applications of phosphorus and zinc to unlimed Crowley silt loam, pH 5.3, on the ratio of the concentration of phosphorus and zinc in plant tissue of *Oryza sativa* L., cultivar Saturn, at three growth and development phases are presented in Table 6. The phosphorus and zinc ratios varied from 2.18 for the rice plants approaching maturity that were grown on soil that received 3.6 ppm of zinc and no phosphorus to 93.23 for rice plants at the vegetative growth phase that received 7.2 ppm of zinc and 400 ppm of phosphorus . According to Warnock (72), zinc deficiency in *Zea mays* L. was encounted when the phosphorus to zinc ratio varied from 100 to 350.

Irrespective to the rates of zinc used, the highest phosphorus to zinc ratios occured when 400 ppm of phosphorus was applied and the rice plants were harvested at the vegetative growth phase. When 50, 100 and 200 ppm of phosphorus were

Table 6 .- The effects of applications of phosphorus and zinc to unlimed Crowley silt loam[1/], pH 5.3, on the ratio of the concentration of phosphorus and zinc in plant tissue of Oryza sativa L., cultivar Saturn, at three growth and development phases.

Treatments		Growth and development phases		
P	Zn	Vegetative[2/]	Reproductive[3/]	Ripening[4/]
ppm			P:Zn ratio	
0	0	11.00	17.50	2.57
0	1.8	9.33	5.31	2.27
0	3.6	10.15	6.34	2.18
0	7.2	4.93	7.45	2.80
50	0	65.61	28.71	13.41
50	1.8	42.81	27.80	12.75
50	3.6	43.08	25.34	10.85
50	7.2	36.71	25.93	13.54
100	0	64.41	37.56	17.70
100	1.8	50.06	33.08	17.09
100	3.6	51.88	40.16	15.40
100	7.2	42.58	29.66	12.13
200	0	86.36	46.04	18.27
200	1.8	70.41	36.86	19.53
200	3.6	63.53	37.94	16.30
200	7.2	53.92	33.74	14.22
400	0	92.88	52.08	22.62
400	1.8	89.62	39.59	20.27
400	3.6	84.64	45.17	19.89
400	7.2	93.23	43.97	20.64

1/ The untreated soil contained 12 ppm of extractable phosphorus and 1.3 ppm of extractable zinc.
2/ Four plants were harvested 61 days after planting.
3/ Three plants were harvested 88 days after planting.
4/ One plant was harvested 125 days after planting.

applied to the soil, the addition of supplementary zinc resulted in lower phosphorus to zinc ratios calculated from the concentration of phosphorus and zinc in the rice plant tissue at the three growth and development phases. The application of zinc to the soil that received 400 ppm of phosphorus had no consistant effect on the phosphorus to zinc ratio.

The data in Table 7 show the effects of applications of phosphorus and zinc to unlimed Crowley silt loam, pH 5.3, on the ratio of the uptake of phosphorus and zinc in plant tissue of *Oryza sativa* L., cultivar Saturn, at three growth and development phases. The results indicate that with the exception of the no phosphorus treatment, higher phosphorus to zinc ratios were calculated for rice at the vegetative phase as compared to rice at the reproductive and ripening phases of growth and development. A high phosphorus to zinc ratio indicates that the uptake of phosphorus by the rice plants is greater when the plants are at the vegetative growth phase. The application of zinc at rates of 1.8, 3.6 and 7.2 ppm to the soil that received 50, 100 and 200 ppm of phosphorus resulted in a reduction in phosphorus to zinc ratio in the rice plants at the vegetative phase of growth. The reduction in the phosphorus to zinc ratio was attributed to an increase in the uptake of zinc resulting from the application of zinc. The application of the different rates of zinc to the soil that received 50, 100 and 200 ppm of phosphorus did not result in a significant reduction in the phosphorus to zinc ratio in the rice plants at the reproductive and ripening phases of growth and development.

Table 7 .-The effects of applications of phosphorus and zinc to unlimed Crowley silt loam[1], pH 5.3, on the ratio of the uptake of phosphorus and zinc in plant tissue of Oryza sativa L., cultivar Saturn, at three growth and development phases.

Treatments		Growth and development phases		
P	Zn	Vegetative[2]	Reproductive[3]	Ripening[4]
ppm		P:Zn ratio		
0	0	10.96	17.37	2.55
0	1.8	9.42	5.25	2.24
0	3.6	10.18	6.34	2.19
0	7.2	4.91	7.37	2.81
50	0	65.76	27.98	13.41
50	1.8	43.03	27.56	12.65
50	3.6	43.45	25.51	10.87
50	7.2	36.67	25.85	13.50
100	0	65.48	34.09	17.67
100	1.8	50.48	33.17	16.99
100	3.6	52.42	39.57	15.30
100	7.2	43.00	29.74	12.10
200	0	66.88	45.56	18.38
200	1.8	56.65	36.43	19.65
200	3.6	62.85	37.65	16.38
200	7.2	54.45	33.67	14.30
400	0	92.07	51.81	22.56
400	1.8	91.08	40.07	20.13
400	3.6	84.02	45.37	19.99
400	7.2	94.20	43.87	20.54

[1]The untreated soil contained 12 ppm of extractable phosphorus and 1.3 ppm of extractable zinc.

[2]Four plants were harvested 61 days after planting.

[3]Three plants were harvested 88 days after planting.

[4]One plant was harvested 125 days after planting.

The effects of applications of phosphorus and zinc on the production of dry matter, the concentration of phosphorus and zinc, the uptake of phosphorus and zinc, the ratio of the concentration of phosphorus and zinc and the ratio of the uptake of phosphorus and zinc by Oryza sativa L., cultivar Saturn, at three phases of growth and development on limed Crowley silt loam, pH 6.3, are presented in Tables 8, 9, 10, 11, 12, 13, 14 and 15.

The data in Table 8 and in Figures 11, 12, 13, and 14 show the effects of applications of phosphorus and zinc on the production of dry matter of Oryza sativa L., cultivar Saturn, at three growth and development phases on limed Crowley silt loam, pH 6.3, The data indicate that a low level of production of dry matter was obtained on the soil that did not receive phosphorus. Plants grown on the soil where no supplementary phosphorus was added were very unthrifty and a reduction in tillering was noted. The leaves of the rice plants at the vegetative growth phase were light green and the lower leaves became chlorotic and necrotic. A consistant increase in the total production of dry matter was obtained with each of the increments of applied phosphorus. Increases in the production of dry matter of rice plants at the vegetative, reproductive and ripening phases of growth and development were also obtained following applications of each of the rates of phosphorus employed. The application of 50 ppm of phosphorus resulted in a two fold increase in dry matter. The application of zinc to the soil where no phosphorus was added did not significantly increase the production of dry matter of rice at the vegetative and reproductive growth phase. The application

Table 8.-The effects of applications of phosphorus and zinc on the production of dry matter of *Oryza sativa* L., cultivar Saturn, at three growth and development phases on limed Crowley silt loam[1], pH 6.3.

Treatments		Growth and development phases			
P	Zn	Vegetative[2]	Reproductive[3]	Ripening[4]	Total
ppm		Dry matter, g/pot, av. of 4 reps.			
0	0	1.01	.81	2.25	4.07
0	1.8	1.11	1.13	3.23	5.47
0	3.6	1.04	1.20	4.10	6.34
0	7.2	1.36	1.45	4.88	7.69
50	0	2.99	3.05	5.26	11.30
50	1.8	3.88	4.28	5.90	14.06
50	3.6	6.19	6.58	6.58	19.35
50	7.2	6.85	6.98	7.78	21.61
100	0	4.61	5.16	5.00	14.77
100	1.8	6.37	6.67	4.65	17.69
100	3.6	7.17	7.58	7.15	21.90
100	7.2	8.92	9.42	8.68	27.02
200	0	5.82	6.11	4.92	16.85
200	1.8	7.52	8.06	6.15	21.73
200	3.6	8.80	8.93	7.35	25.08
200	7.2	9.88	10.73	9.00	29.61
400	0	6.85	7.38	4.18	18.41
400	1.8	8.69	9.13	5.41	23.23
400	3.6	9.18	9.53	6.52	25.23
400	7.2	10.28	10.66	7.73	28.67
LSD, 5%		1.62	0.80	0.98	3.72

1/The untreated soil contained 12 ppm of extractable phosphorus and 1.3 ppm of extractable zinc.

2/Four plants were harvested 61 days after planting.

3/Three plants were harvested 88 days after planting.

4/One plant was harvested 125 days after planting.

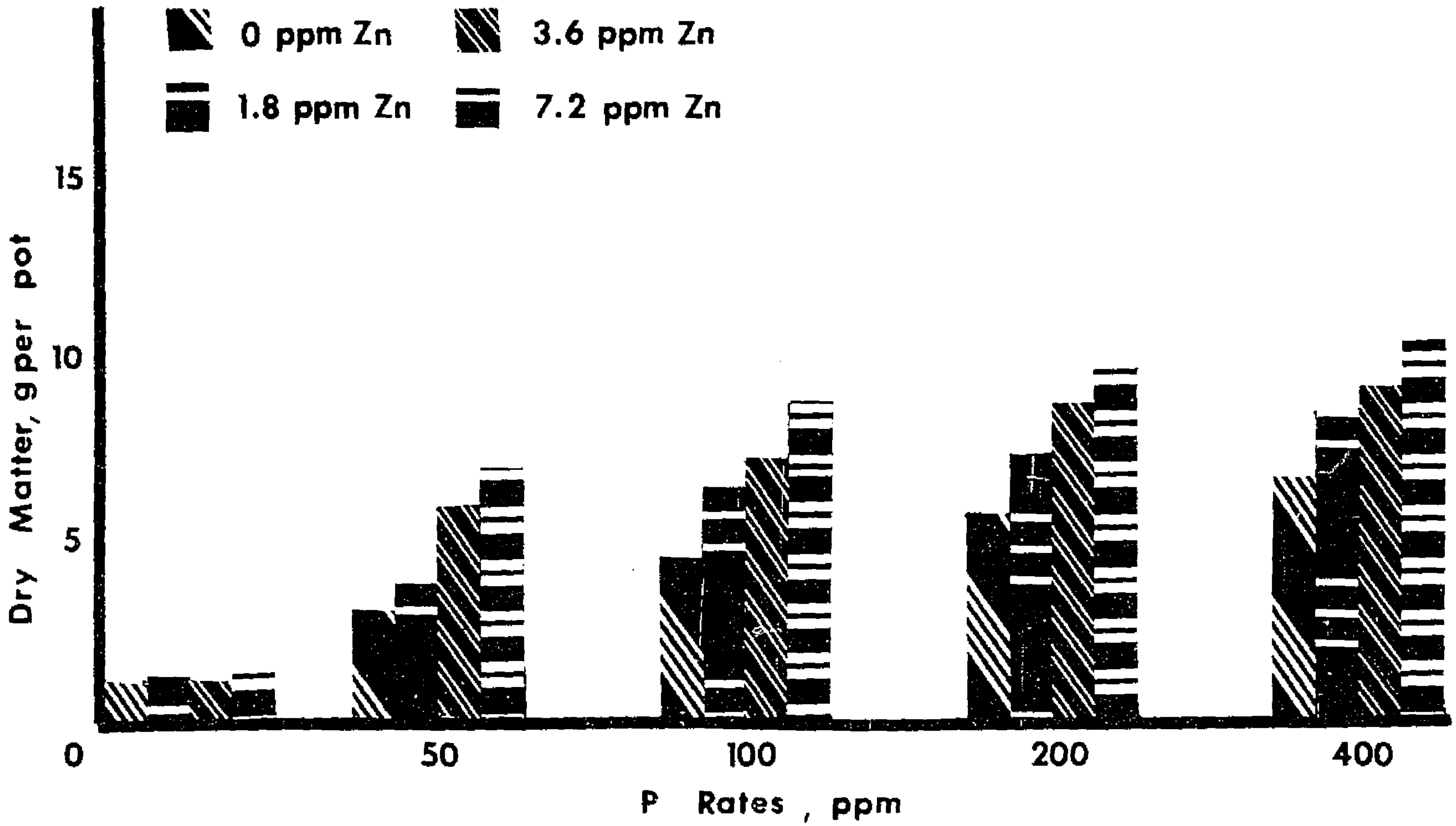

Fig. 11.- The effects of applications of phosphorus and zinc on the production of dry matter of Oryza sativa L., cultivar Saturn, at the vegetative phase of growth and development on limed Crowley silt loam, pH 6.3.

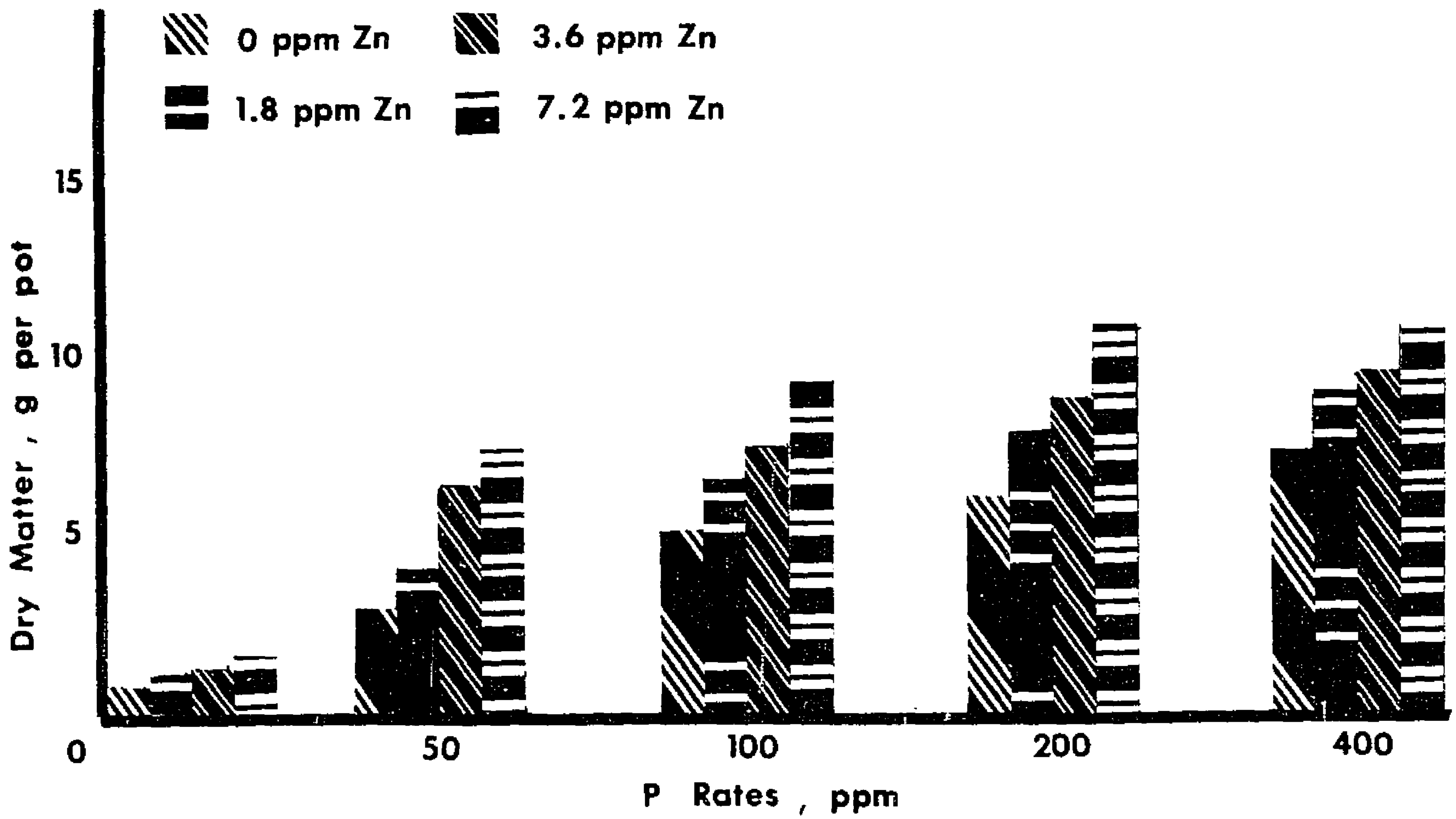

Fig. 12.- The effects of applications of phosphorus and zinc on the production of dry matter of Oryza sativa L., cultivar Saturn, at the reproductive phase of growth and development on limed Crowley silt loam, pH 6.3.

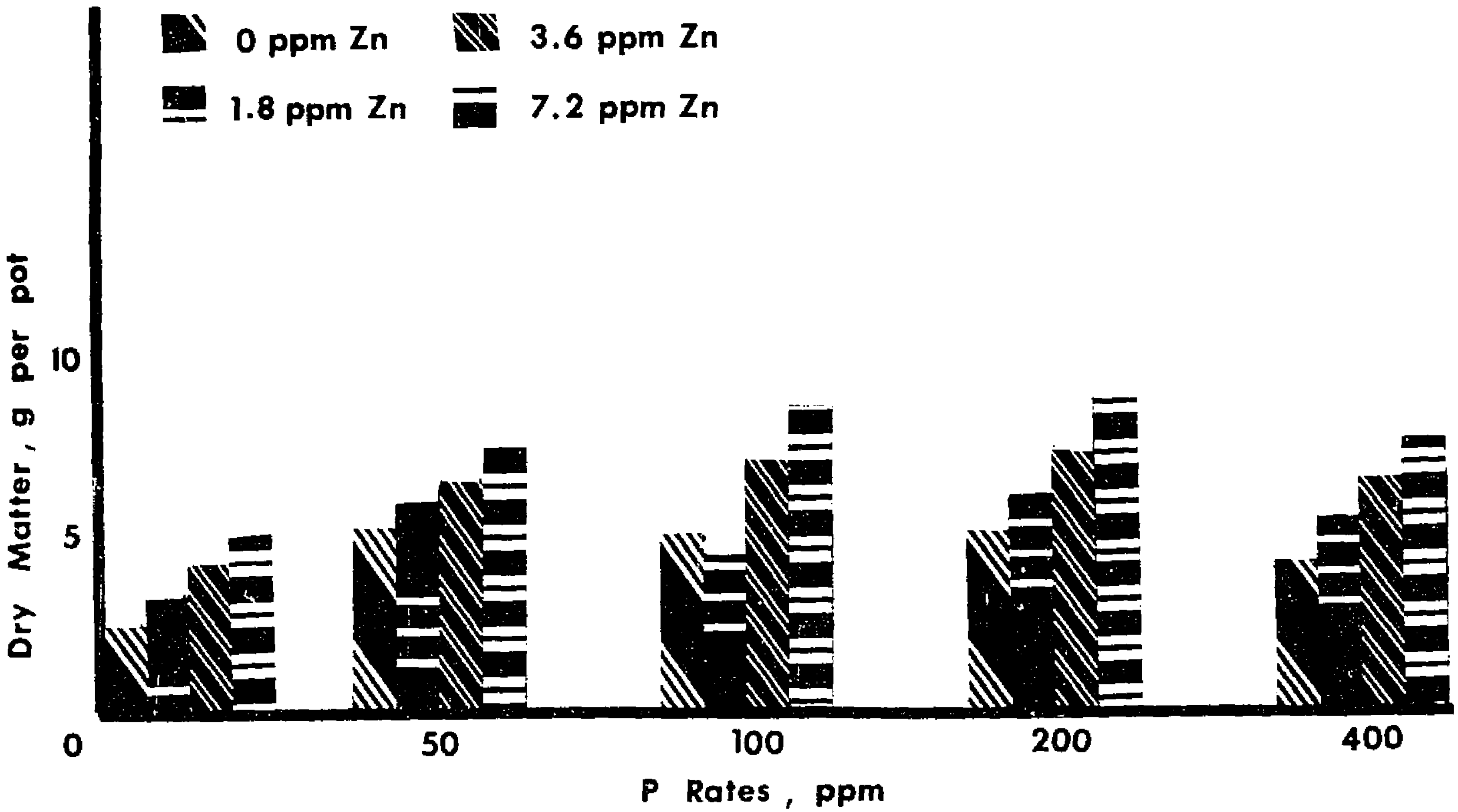

Fig. 13.- The effects of applications of phosphorus and zinc on the production of dry matter of Oryza sativa L., cultivar Saturn, at the ripening phase of growth and development on limed Crowley silt loam, pH 6.3.

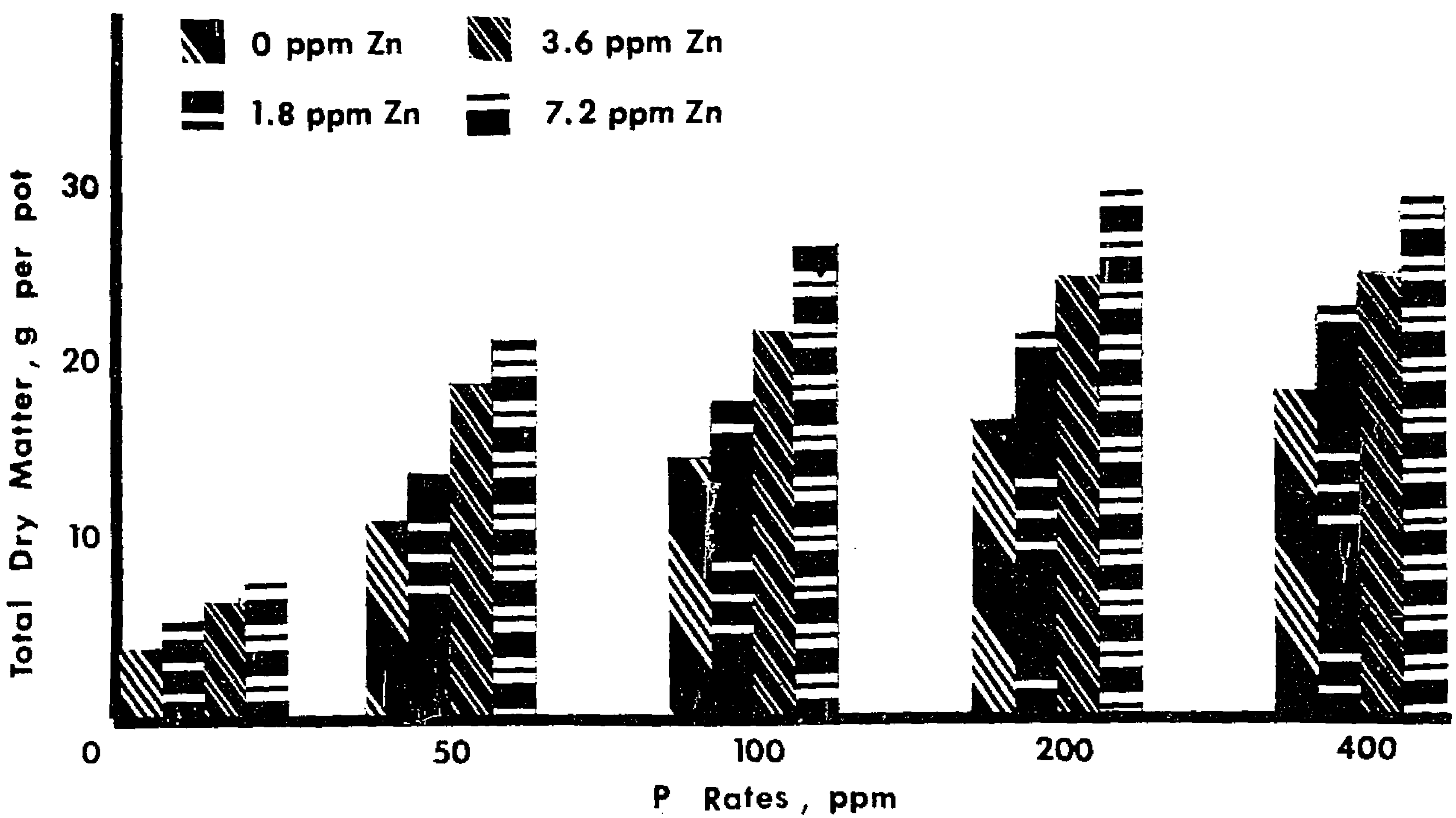

Fig. 14.- The effects of applications of phosphorus and zinc on the total production of dry matter of *Oryza sativa* L., cultivar Saturn, at three growth and development phases on limed Crowley silt loam, pH 6.3.

of 1.8, 3.6 and 7.2 ppm of zinc to the soil that did not receive phosphorus resulted in a significant increase over the check in the production of dry matter of rice plants that were approaching maturity. The data suggest that at the ripening phase of growth, zinc became a limiting factor in the production of dry matter of rice plants grown on soil that did not receive phosphorus. The application of each of the rates of zinc used in conjunction with 50, 100, 200, and 400 ppm of phosphorus resulted in a statistically significant increase in the production of dry matter of rice plants at the three growth and development phases.

A statistically significant interaction was obtained between phosphorus and zinc in the production of dry matter of rice plants at each of the three growth and development phases and in the total yield. The data indicate that the application of high rates of phosphorus did not have a depressing effect on the production of dry matter. However, severe "bronzing" of lower leaves was observed on plants grown on soil that received 400 ppm of phosphorus with and without applied zinc. Some "bromzed" leaves were also noted on plants grown on the soil that received an application of 200 ppm of phosphorus without supplementary zinc. "Bronzing" was characterized by a large number of brown spots which appeared on the lower leaves. The leaves became chlorotic and developed brown spots which developed into a somewhat irregular brown streaks and blotches. Some investigators have reported that "bronzing" is a visual symptom of zinc deficiency (28 and 79). Other investigators have reported that "bronzing" has been corrected with an application of zinc but the abnormality may not be due to a deficiency of zinc alone (52). Unpublished data on file at the Department of Agronomy at Louisiana State University indicate that the leaf tissue of rice that was considered to be relatively low in zinc contained high amounts of iron and manganese. This would indicate that "bronzing" may have been caused by iron or manganese toxicity.

The effects of applications of phosphorus and zinc on the concentration of phosphorus in plant tissue of Oryza sativa L., cultivar Saturn, grown on limed Crowley silt loam, pH 6.3, at three growth and development phases are presented in Table 9. The concentration of phosphorus in the tissue of the rice plants grown on soil that did not receive phosphorus was considered to be critically low at each of the growth and development phases. A statiatically significant increase in the concentration of phosphorus in the plant tissue resulted from the application of 50, 100, 200 and 400 ppm of phosphorus at each of the four rates of applied zinc and at each of the three phases of growth and development. In general, the concentration of phosphorus in plant tissue of the plants at the vegetative phase was higher than that of plants at reproductive and ripening phases.

The application of the different rates of zinc to the soil that did not receive supplementary phosphorus resulted in a slight but non-consistant reduction in the phosphorus concentration in the tissue of rice at the three growth and development phases. The application of 3.6 and 7.2 ppm of zinc to the soil that received 50, 100 and 200 ppm of phosphorus resulted in a significant increase in the phosphorus concentration in the tissue of rice at the three growth phases.

The application of 0, 1.8, 3.6 and 7.2 ppm of zinc and 50 ppm of

Table 9 .-The effects of applications of phosphorus and zinc on the concentration of phosphorus in plant tissue of *Oryza sativa* L., cultivar Saturn, grown on limed Crowley silt loam[1/], pH 6.3, at three growth and development phases.

Treatments		Growth and development phases		
P	Zn	Vegetative[2/]	Reproductive[3/]	Ripening[4/]
ppm			P, ppm	
0	0	430	260	99
0	1.8	368	185	90
0	3.6	496	230	112
0	7.2	338	243	183
50	0	1485	912	725
50	1.8	1569	984	785
50	3.6	1607	1044	783
50	7.2	1639	1072	883
100	0	1671	1188	970
100	1.8	1659	1187	995
100	3.6	1679	1185	998
100	7.2	1718	1140	1040
200	0	1507	1201	1015
200	1.8	1468	1277	1055
200	3.6	1852	1234	1024
200	7.2	1910	1281	1084
400	0	2251	1337	1076
400	1.8	2243	1283	1070
400	3.6	2284	1270	1109
400	7.2	2025	1398	1134
LSD, 5%		27	25	18

[1/]The untreated soil contained 12 ppm of extractable phosphorus and 1.3 ppm of extractable zinc.

[2/]Four plants were harvested 61 days after planting.

[3/]Three plants were harvested 88 days after planting.

[4/]One plant was harvested 125 days after planting.

phosphorus significantly increased the concentration of phosphorus in plant tissue of the rice plants at vegetative and reproductive phases. When the four rates of zinc were applied to the soil that received 0, 100, 200 and 400 ppm of phosphorus, there was no consistant variation in the concentration of phosphorus in plant tissue of the rice plants at three phases of growth and development. The application of 1.8 ppm of zinc to the soil that received 0, 100, 200 and 400 ppm of phosphorus resulted in a reduction in phosphorus concentration of rice plants at vegetative phase. A reduction in the concentration of phosphorus also occurred in rice plants at the reproductive phase when 1.8 ppm of zinc was applied to the soil that received no phosphorus and 400 ppm of phosphorus respectively.

A statistically significant interaction was obtained between the concentration of phosphorus and zinc in the tissue of rice plants at each of the three growth and development phases.

The data in Table 10 show the effects of applications of phosphorus and zinc on the concentration of zinc in the tissue of *Oryza sativa* L., cultivar Saturn, grown on limed Crowley silt loam, pH 6.3, at three growth and development phases. The data indicate that the application of each rate of zinc to the Crowley soil with or without added phosphorus resulted in a consistant increase in the concentration of zinc in the tissue of rice at each of the growth and development phases. Significantly larger concentrations of zinc were found in the tissue of rice plants that were approaching maturity than were found in plants at the vegetative and reproductive phases of growth and development. There was a tendency for the higher rates of

Table 10.-The effects of applications of phosphorus and zinc on the concentration of zinc in plant tissue of Oryza sativa L., cultivar Saturn, grown on limed Crowley silt loam[1/], pH 6.3, at three growth and development phases.

Treatments		Growth and development phases		
P	Zn	Vegetative[2/]	Reproductive[3/]	Ripening[4/]
ppm		Zn, ppm		
0	0	28	10	95
0	1.8	35	16	121
0	3.6	41	22	121
0	7.2	49	23	137
50	0	25	17	112
50	1.8	33	20	130
50	3.6	35	23	147
50	7.2	39	27	153
100	0	28	16	118
100	1.8	33	21	128
100	3.6	33	19	146
100	7.2	38	23	187
200	0	22	15	111
200	1.8	26	21	117
200	3.6	30	21	137
200	7.2	34	22	151
400	0	27	12	98
400	1.8	29	17	106
400	3.6	32	18	122
400	7.2	34	21	127
LSD, 5%		3	2	6

[1/]The untreated soil contained 12 ppm of extractable phosphorus and 1.3 ppm of extractable zinc.

[2/]Four plants were harvested 61 days after planting.

[3/]Three plants were harvested 88 days after planting.

[4/]One plant was harvested 125 days after planting.

phosphorus to reduce the concentration of zinc in the tissue of rice plants at the three growth phases. The depressive effect of applied phosphorus on the concentration of zinc in the rice tissue was observed on the soil that did not receive zinc as well as on the soil that received applications of zinc. The data suggest that phosphorus induced zinc deficiency of rice grown under submerged conditions may result from the excessive use of phosphorus on Crowley silt loam at pH 6.3.

The effects of applications of phosphorus and zinc on the concentration of zinc in plant tissue of Oryza sativa L., cultivar Saturn, grown on limed Crowley silt loam, pH 6.3, at vegetative phase of growth and development are presented in Table 11. The data show the depressive effect that applied phosphorus had on the concentration of zinc in the tissue of rice at the vegetative phase of growth. A pronounced reduction in the concentration of zinc in the plant tissue was noted with increasing rates of applied phosphorus .

A statistically significant interaction was calculated between the concentrations of phosphorus and zinc in the plant tissue. These data are not in agreement with the results obtained by investigators at The International Rice Research Institute in Philippines who reported that " a heavy application of phosphate did not cause a zinc deficiency in rice grown on submerged soil ."

The effects of applications of phosphorus and zinc to limed Crowley silt loam, pH 6.3, on the uptake of phosphorus by Oryza sativa L., cultivar Saturn, at three growth and development phases are presented in Table 12 and in Figures 15, 16 and 17. The data indicate that a very small quantity of phosphorus was taken up by the rice plants grown on soil that did not receive an application of phosphorus.

Table 11.- The effects of applications of phosphorus and zinc on the concentration of zinc in plant tissue of *Oryza sativa* L., cultivar Saturn, grown on limed Crowley silt loam1/, pH 6.3, at the vegetative phase of development.

P rates	Zn rates , ppm			
	0	1.8	3.6	7.2
ppm	Zn, ppm			
0	28	35	41	49
50	25	33	35	39
100	28	33	33	38
200	22	26	30	34

1/ The untreated soil contained 12 ppm of extractable phosphorus and 1.3 ppm of extractable zinc.

Table 12.- The effects of applications of phosphorus and zinc to limed Crowley silt loam[1/], pH 6.3, on the uptake of phosphorus by *Oryza sativa* L.,cultivar Saturn, at three growth and development phases.

Treatments		Growth and development phases		
P		Vegetative[2/]	Reproductive[3/]	Ripening[4/]
ppm		P, mgm per pot		
0	0	0.44	0.37	0.56
0	1.8	0.41	0.32	0.74
0	3.6	0.52	0.40	1.07
0	7.2	0.46	0.64	1.58
50	0	4.44	3.39	4.75
50	1.8	6.09	4.64	5.46
50	3.6	9.95	7.53	6.47
50	7.2	11.23	8.88	8.43
100	0	7.71	7.16	5.85
100	1.8	10.57	8.92	5.56
100	3.6	12.04	10.28	8.43
100	7.2	15.33	12.63	10.77
200	0	8.77	8.56	5.91
200	1.8	11.04	11.91	7.72
200	3.6	16.30	12.81	9.00
200	7.2	18.88	15.25	11.56
400	0	15.42	10.61	5.34
400	1.8	19.50	13.27	6.88
400	3.6	20.97	14.01	8.49
400	7.2	20.82	16.18	10.32
LSD, 5%		1.25	0.96	1.17

1/ The untreated soil contained 12 ppm of extractable phosphorus and 1.3 ppm of extractable zinc.
2/ Four plants were harvested 61 days after planting.
3/ Three plants were harvested 88 days after planting.
4/ One plant was harvested 125 days after planting.

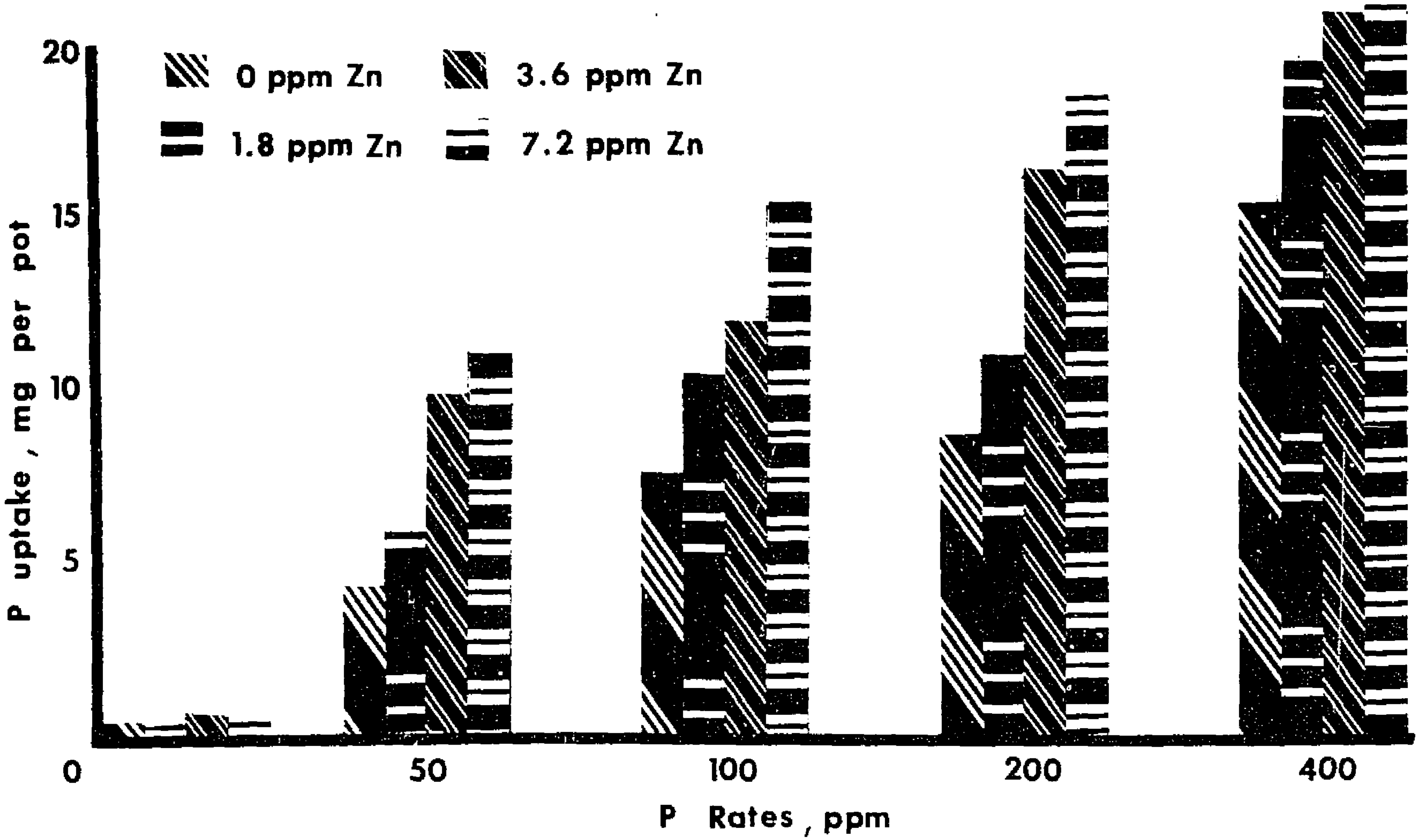

Fig. 15.- The effects of applications of phosphorus and zinc to limed Crowley silt loam, pH 6.3, on the uptake of phosphorus by *Oryza sativa* L., cultivar Saturn, at the vegetative phase of growth and development.

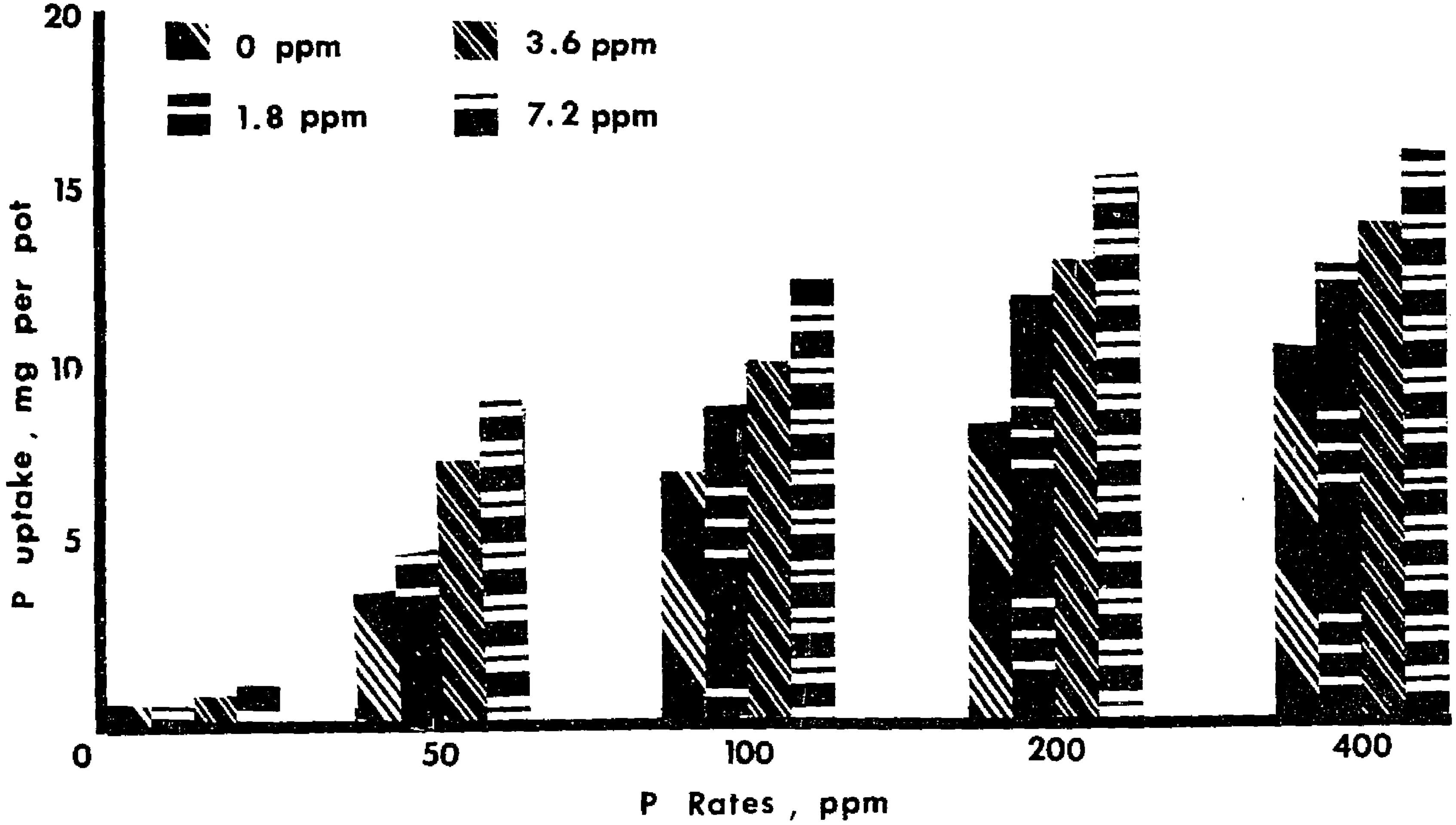

Fig. 16.- The effects of applications of phosphorus and zinc to limed Crowley silt loam, pH 6.3, on the uptake of phosphorus by *Oryza sativa* L., cultivar Saturn, at the reproductive phase of growth and development.

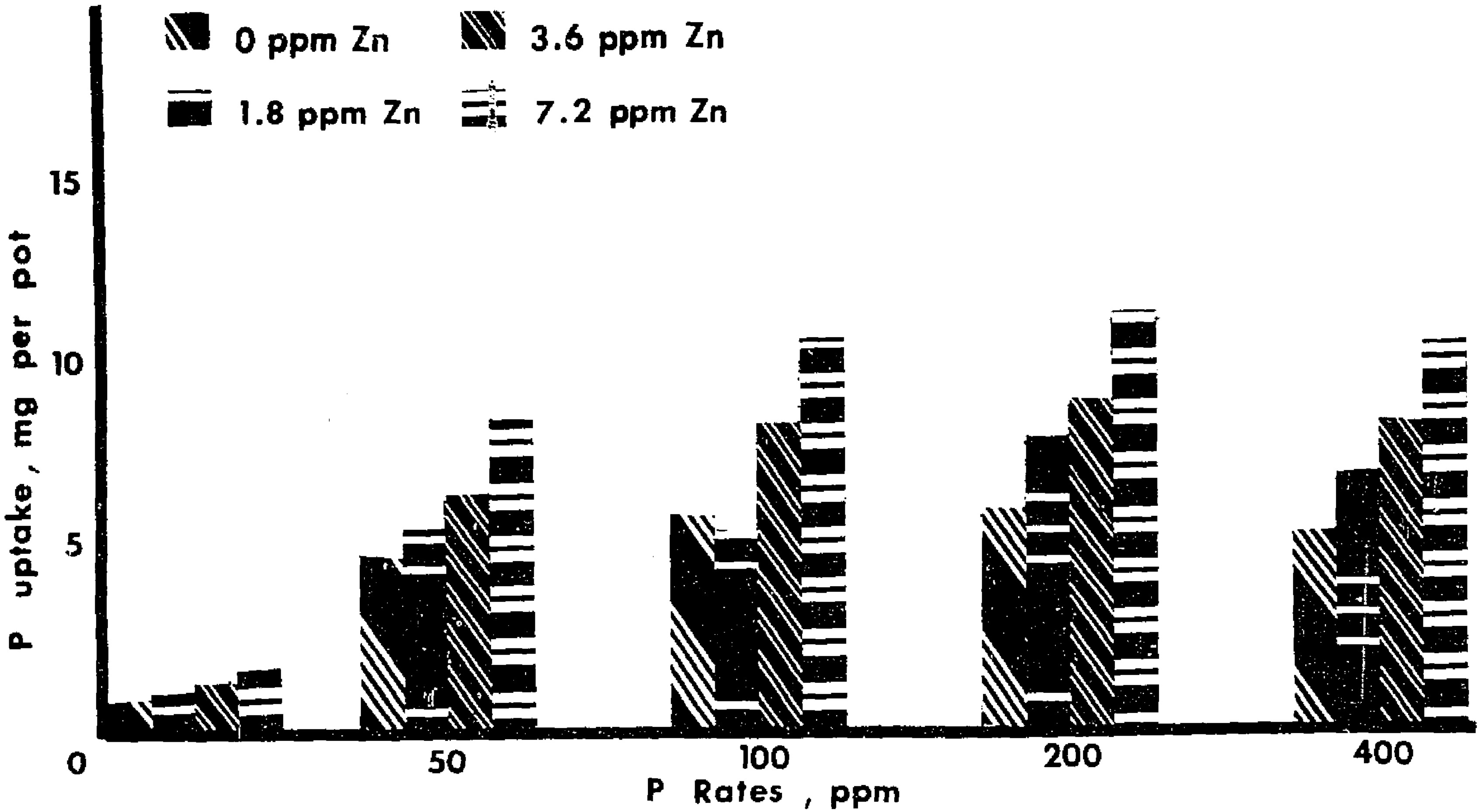

Fig. 17.- The effects of applications of phosphorus and zinc to limed Crowley silt loam, pH 6.3, on the uptake of phosphorus by *Oryza sativa* L., cultivar Saturn, at the ripening phase of growth and development.

The low amount of phosphorus absorbed by the rice plants was attributed to the low concentration of soluble phosphorus that was found in the untreated soil. On soils that did not receive supplementary phosphorus, total production of dry matter was low and the concentration of phosphorus was considerably below 0.10% which is considered to be a critically low value. The application of 50, 100, 200 and 400 ppm of phosphorus resulted in significant increases in the uptake of phosphorus by the rice plants. When the rates of phosphorus were used in conjunction with applications of zinc, further increases in the uptake of phosphorus were noted. The data suggest that the applications of zinc increased the ability of the rice plant to absorb greater amounts of applied phosphorus from the soil. The application of zinc to the soil that did not receive phosphorus had no effect on the uptake of phosphorus by the rice plants at any of the growth phases. The data indicate that application of zinc did not induce phosphorus deficiency on the Crowley soil, pH 6.3, that contained 12 ppm of extractable phosphorus.

The data in Table 13 and in Figures 18, 19 and 20 show the effects of applications of phosphorus and zinc to limed Crowley silt loam, pH 6.3, on the uptake of zinc by *Oryza sativa* L., cultivar Saturn, at three growth and development phases. The application of each of the rates of zinc to the soil that did not receive phosphorus resulted in a consistant but nonsignificant increase in the uptake of zinc by the rice plants at each of the growth phases. A considerably larger quantity of zinc was absorbed by the plants that approached maturity than was taken up by plants at the vegetative and reproductive phases. The increase uptake of zinc by the

Table 13.-The effects of applications of phosphorus and zinc to limed Crowley silt loam[1/], pH 6.3, on the uptake of zinc by *Oryza sativa* L., cultivar Saturn, at three growth and development phases.

Treatments		Growth and development phases		
P	Zn	Vegetative[2/]	Reproductive[3/]	Ripening[4/]
ppm		Zn , µg per pot		
0	0	28	9	216
0	1.8	40	19	392
0	3.6	43	27	496
0	7.2	67	34	670
50	0	76	55	592
50	1.8	130	89	770
50	3.6	222	156	968
50	7.2	271	195	1194
100	0	129	85	592
100	1.8	212	146	598
100	3.6	241	145	1046
100	7.2	346	223	1628
200	0	131	96	550
200	1.8	200	176	720
200	3.6	266	190	1008
200	7.2	340	245	1368
400	0	185	93	411
400	1.8	260	163	576
400	3.6	296	176	798
400	7.2	352	225	985
LSD, 5%		34	28	156

1/ The untreated soil contained 12 ppm of extractable phosphorus and 1.3 ppm of extractable zinc.
2/ Four plants were harvested 61 days after planting.
3/ Three plants were harvested 88 days after planting.
4/ One plant was harvested 125 days after planting.

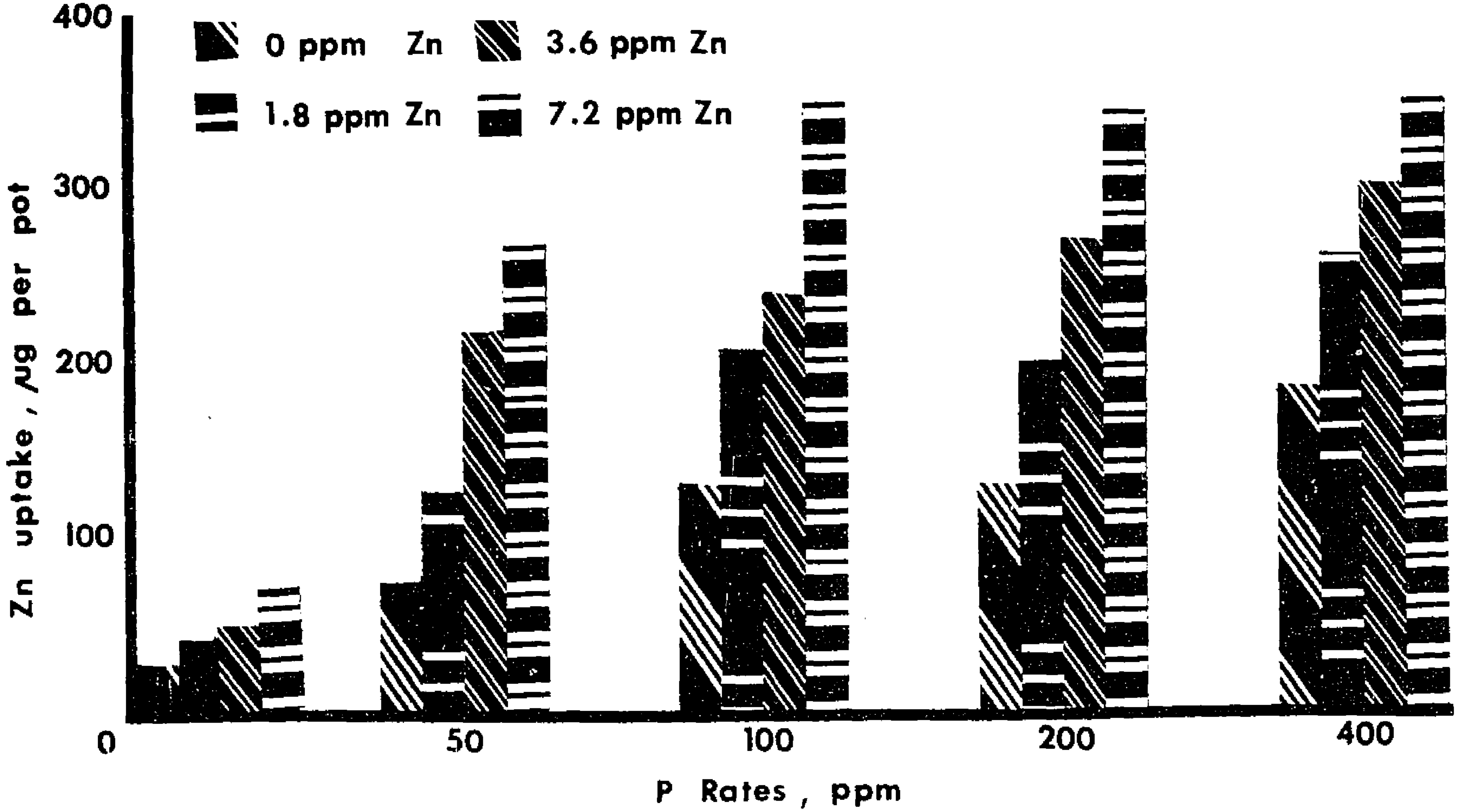

Fig. 18.- The effects of applications of phosphorus and zinc to limed Crowley silt loam, pH 6.3, on the uptake of zinc by Oryza sativa L., cultivar Saturn, at the vegetative phase of growth and development.

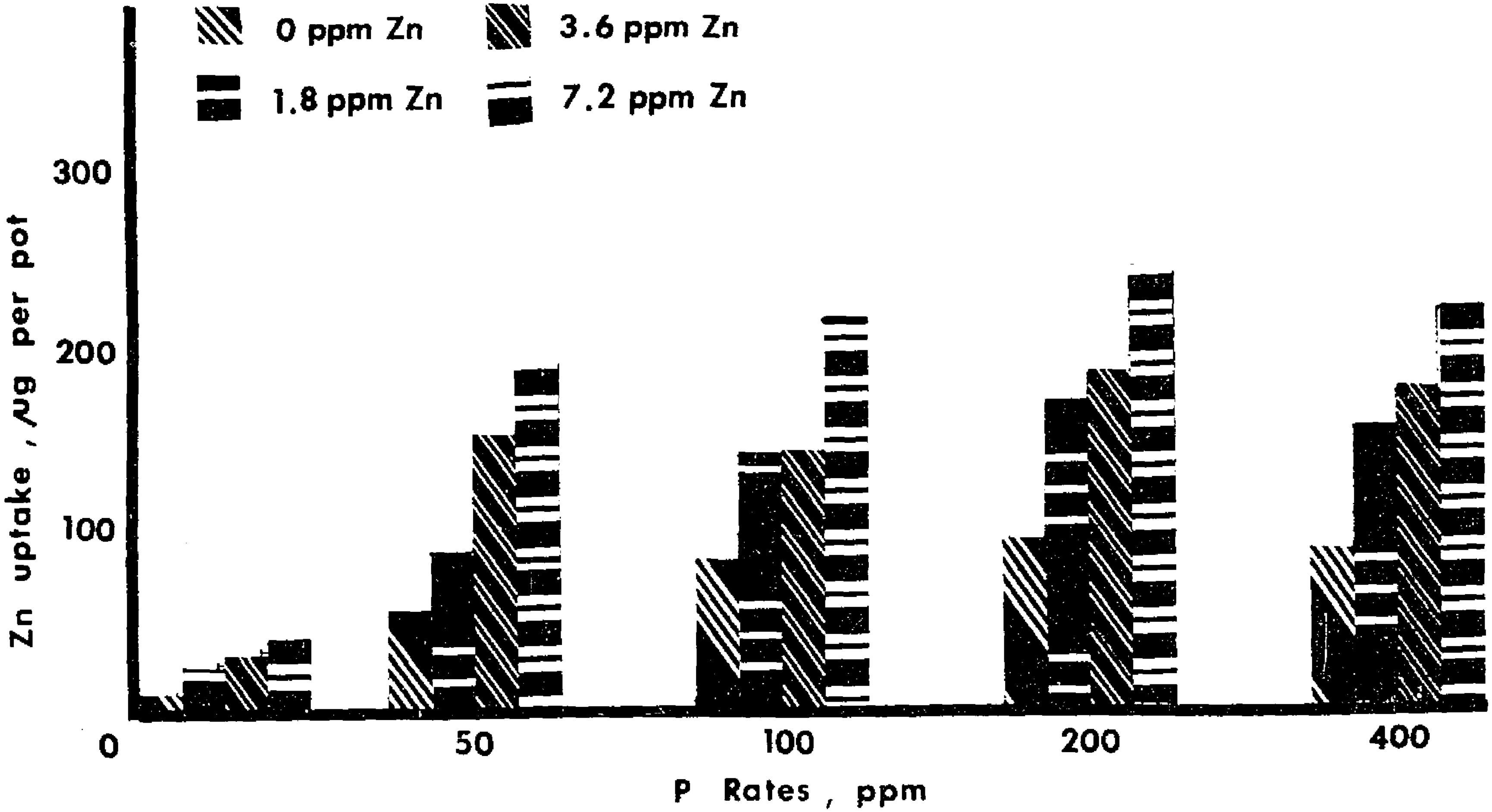

Fig. 19.- The effects of applications of phosphorus and zinc to limed Crowley silt loam, pH 6.3, on the uptake of zinc by *Oryza sativa* L., cultivar Saturn, at the reproductive phase of growth and development.

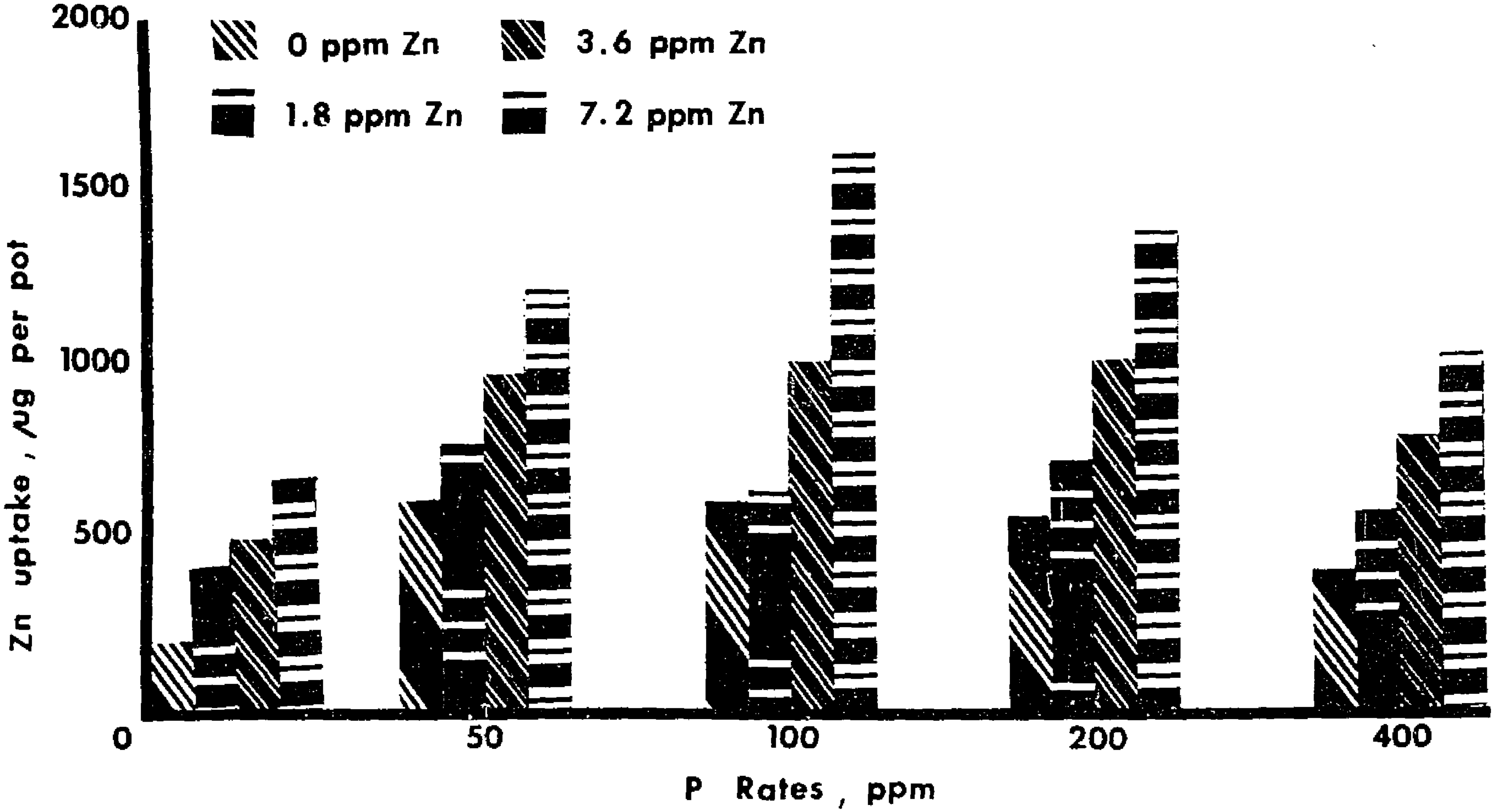

Fig. 20.- The effects of applications of phosphorus and zinc to limed Crowley silt loam, pH 6.3, on the uptake of zinc by *Oryza sativa* L., cultivar Saturn, at the ripening phase of growth and development.

mature rice plants was attributed to the larger quantity of dry matter produced and to the relatively high concentration of zinc found in the tissue. In general, the application of 1.8, 3.6 and 7.2 ppm of zinc to the soil that received 50, 100, 200 and 400 ppm of phosphorus resulted in a significant increase in the uptake of zinc by plants at each of the three growth phases.

A statistically significant interaction was obtained between the phosphorus and the zinc treatments on the uptake of zinc in the plant tissue of rice plants at each of the three growth and development phases. The data show that the application of phosphorus at the rates of 50, 100, 200 and 400 ppm did not depress the absorption of zinc from the soil by the rice plants. It was noted that the application of phosphorus resulted in a significant reduction in the concentration of zinc in the plant tissue. However, the response, measured by increased production of dry matter, resulting from the phosphorus treatments was highly significant. The increases obtained in the uptake of zinc by the rice plants grown on soil that received the different rates of phosphorus was attributed to the increased yield.

The effects of applications of phosphorus and zinc to limed Crowley silt loam, pH 6.3, on the ratio of the concentration of phosphorus and zinc in plant tissue of Oryza sativa L., cultivar Saturn, at three growth and development phases are presented in Table 14. The phosphorus and zinc ratios varied from 0.74 for the rice plants approaching maturity and grown on soil that received 1.8 ppm of zinc to 111.42 for rice plants at the reproductive phase that received 400 ppm of phosphorus. The phosphorus to zinc ratio of 111.42 was

Table 14 .- The effects of applications of phosphorus and zinc to limed Crowley silt loam[1/], pH 6.3, on the ratio of the concentration of phosphorus and zinc in plant tissue of *Oryza sativa* L., cultivar Saturn, at three growth and development phases.

Treatments		Growth and development phases		
P	Zn	Vegetative[2/]	Reproductive[3/]	Ripening[4/]
ppm			P:Zn ratio	
0	0	15.36	26.00	1.04
0	1.8	10.51	11.56	0.74
0	3.6	12.10	10.45	0.93
0	7.2	6.90	10.57	1.34
50	0	59.40	53.65	6.47
50	1.8	47.55	49.20	6.04
50	3.6	45.91	45.39	5.33
50	7.2	42.03	39.70	5.77
100	0	59.68	74.25	8.22
100	1.8	50.27	56.52	7.72
100	3.6	50.88	62.37	6.84
100	7.2	45.21	49.57	5.56
200	0	68.50	80.07	9.14
200	1.8	56.46	60.81	9.02
200	3.6	61.73	58.76	7.47
200	7.2	56.18	58.23	7.18
400	0	83.37	111.42	10.98
400	1.8	77.34	75.47	10.09
400	3.6	71.38	70.56	9.09
400	7.2	59.56	66.57	8.93

1/ The untreated soil contained 12 ppm of extractable phosphorus and 1.3 ppm of extractable zinc.
2/ Four plants were harvested 61 days after planting.
3/ Three plants were harvested 88 days after planting.
4/ One plant was harvested 125 days after planting.

the highest value calculated. Rice plants at the reproductive phase of development grown on soil that received 400 ppm of phosphorus alone exhibited acute symptoms of zinc deficiency. They were severely " bronzed ," however the production of dry matter was not severely depressed. The results are in agreement with those obtained by Warnock (72). He reported that zinc deficiency in corn was observed when the ratio of the concentration of phosphorus to zinc in the leaf tissue of corn approached 100. In general, the ratios of the concentration of phosphorus and zinc in the tissue of the rice plants at the ripening phase is lower than that at the vegetative and reproductive phases. At the ripening phase of development, rice plants contain considerably larger amounts of zinc and smaller amounts of phosphorus than they do at other phases of growth and development. This accounts for the lower P:Zn ratios calculated between the concentration of phosphorus and zinc in the rice plants as they approach maturity. When the rates of phosphorus used was increased from 0 to 50, 100, 200 and 400 ppm a consistant increase in the ratio of the concentration of phosphorus and zinc in the plant tissue of the rice plants at each of the three growth phases was observed. At each rate of applied phosphorus, the application of 1.8, 3.6 and 7.2 ppm of zinc resulted in a significant decrease in the ratio of the concentration of phosphorus and zinc in the plant tissue.

The data in Table 15 show the effects of applications of phosphorus and zinc to limed Crowley silt loam, pH 6.3, on the ratio of the uptake of phosphorus and zinc in plant tissue of *Oryza sativa* L., cultivar Saturn, at three growth and development phases.

Table 15.-The effects of applications of phosphorus and zinc to limed Crowley silt loam[1], pH 6.3, on the ratio of the uptake of phosphorus and zinc in plant tissue of *Oryza sativa* L., cultivar Saturn, at three growth and development phases.

Treatments		Growth and development phases		
P	Zn	Vegetative[2]	Reproductive[3]	Ripening[4]
ppm		P:Zn ratio		
0	0	15.54	41.44	2.59
0	1.8	10.20	17.00	1.90
0	3.6	12.00	14.70	2.15
0	7.2	6.88	18.91	2.35
50	0	58.43	61.71	8.02
50	1.8	46.85	52.16	7.09
50	3.6	44.81	48.28	6.69
50	7.2	41.44	45.56	7.06
100	0	59.74	84.27	9.88
100	1.8	49.86	61.10	9.30
100	3.6	49.95	70.86	8.06
100	7.2	44.30	56.61	6.61
200	0	66.98	89.19	10.74
200	1.8	55.21	67.64	10.72
200	3.6	61.29	67.40	8.93
200	7.2	55.53	62.23	8.45
400	0	83.36	114.03	12.98
400	1.8	74.98	81.43	11.94
400	3.6	70.83	79.63	10.63
400	7.2	59.16	71.92	10.47

1/The untreated soil contained 12 ppm of extractable phosphorus and 1.3 ppm of extractable zinc.

2/Four plants were harvested 61 days after planting.

3/Three plants were harvested 88 days after planting.

4/One plant was harvested 125 days after planting.

The application of 1.8, 3.6 and 7.2 ppm of zinc to the soil that did not receive phosphorus and to the soil that received the different rates of phosphorus resulted in a somewhat consistant decrease in the phosphorus to zinc ratios calculated from the uptake of phosphorus and zinc by the rice plants. The application of phosphorus resulted in a significant increase in the yield of dry matter, the concentration of phosphorus in the tissue and the phosphorus to zinc ratio based on the uptake of phosphorus and zinc by the rice plants. The relatively low P:Zn ratios obtained for rice plants that were approaching maturity indicated that the phosphorus uptake at this phase of growth and development was somewhat low while the uptake of zinc from the soil was relatively high.

The effects of applications of zinc and different sources of phosphorus on the production of dry matter of Oryza sativa L., cultivar Saturn, grown on unlimed Crowley silt loam, pH 5.3, are presented in Table 16 and in Figure 21. The data indicate that a significant response to phosphorus was obtained from all of the sources applied to the soil that did not receive zinc as well as the soil that received supplementary zinc. The results show that on the Crowley silt loam soil that did not receive an application of zinc, normal superphosphate was superior to CSP, DAP and MAP, but it was not a better source of phosphorus than APP for the production of dry matter of rice plants harvested at the vegetative phase of growth and development. On the soil that did not receive supplementary zinc, the application of ammonium polyphosphate resulted in a higher production of dry matter than did the application of DAP and MAP. However, the yield of dry matter obtained on soils that

Table 16 .- The effects of applications of zinc and different sources of phosphorus on the production of dry matter of *Oryza sativa* L., cultivar Saturn, grown on unlimed Crowley silt loam1/, pH 5.3.

Phosphorus sources	Symbol	Dry matter		
		No Zn	Zn	Difference
		grams per pot		
No phosphorus		0.98	1.13	0.15
Normal superphosphate, 8.95%P	NSP	6.05	7.36	1.31
Concentrated superphosphate, 20.24%P	CSP	5.40	6.41	1.01
Diammonium phosphate, 23.32% P	DAP	5.02	6.15	1.13
Monoammonium phosphate, 27.82% P	MAP	5.02	6.04	1.02
Ammonium polyphosphate, 27.28% P	APP	5.70	7.06	1.36

LSD, 5 % for P sources: 0.41
LSD, 5% for Zn treatments: 0.51

1/ The untreated soil contained 12 ppm of extractable phosphorus and 1.3 ppm of extractable zinc.
2/ The phosphorus sources were applied at a rate equivalent to 50 ppm of P.
3/ Eight plants per pot, harvested at 64 days after planting.

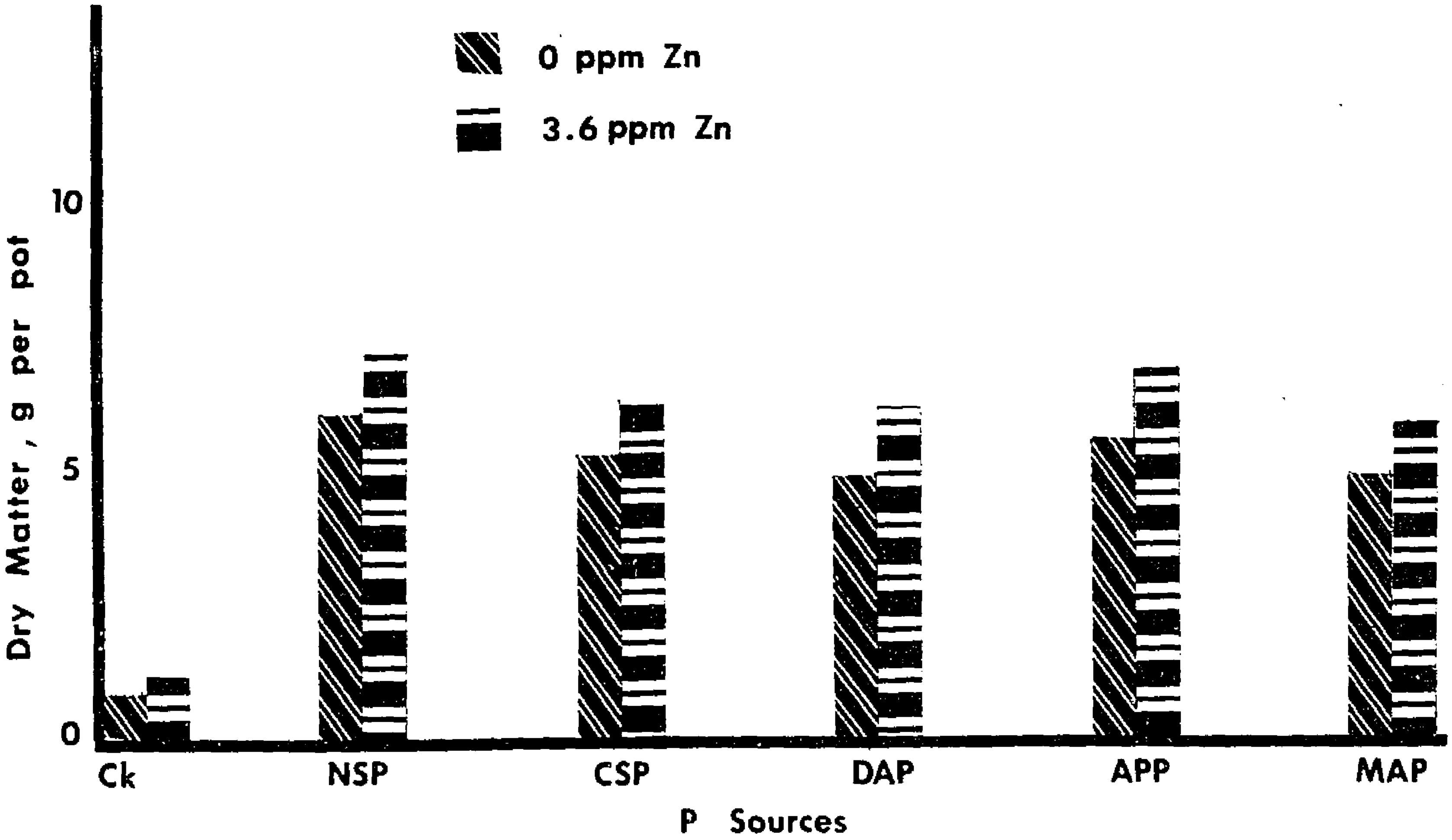

Fig. 21.- The effects of applications of zinc and different sources of phosphorus on the production of dry matter of <u>Oryza sativa</u> L., cultivar Saturn, grown on unlimed Crowley silt loam, pH 5.3.

received APP was not significantly larger than the yield obtained following an application of CSP. The application of MAP and DAP without supplementary zinc resulted in relatively low yields of dry matter and were considered to be the least effective sources of phosphorus used in the investigation. When zinc was applied to the soil , normal superphosphate and ammonium polyphosphate were found to be superior to the other sources of phosphorus in the production of dry matter. There were no statistical differences in the production of dry matter of rice grown on the soil that received zinc and CSP, DAP and MAP. The data in Table 16 show that on the soil that did not receive phosphorus, the application of zinc did not result in a significant increase in yield. When zinc was applied with all of the sources of phosphorus, a significant increase in yield was recorded.

The data in Table 17 show the effects of applications of different sources of phosphorus on the concentration of phosphorus and zinc in plant tissue of Oryza sativa L., cultivar Saturn,grown on unlimed Crowley silt loam, pH 5.3. When no zinc was applied to the soil, the phosphorus concentration in plant tissue of rice plants that received NSP, CSP, and APP was significantly higher than that of the check. Rice plants grown on the soil that received DAP and MAP did not contain a significantly higher phosphorus concentration than did the plants grown on the soil that did not receive phosphorus. The application of CSP with or without zinc resulted in the highest concentration of phosphorus in the rice tissue. On the soil that received zinc, the application of NSP, CSP, MAP and APP resulted in significantly high concentrations of phosphorus in the rice tissue

Table 17 .- The effects of applications of zinc and different sources of phosphorus on the concentration of phosphorus in plant tissue of *Oryza sativa* L., cultivar Saturn, grown on unlimed Crowley silt loam1/, pH 5.3.

Phosphorus sources	Symbol	P No Zn	P Zn	Zn No Zn	Zn Zn
			ppm		
No phosphorus		203	202	28	28
Normal superphosphate, 8.95% P	NSP	220	219	25	27
Concentrated superphosphate, 20.24%P	CSP	233	234	24	25
Diammonium phosphate, 23.32% P	DAP	210	208	23	24
Monoammonium phosphate, 27.82% P	MAP	215	218	24	26
Ammonium polyphosphate, 27.28% P	APP	218	219	23	22
LSD, 5% for P sources		13		3	
LSD, 5% for Zn treatments		0.45		0.72	

1/ The untreated soil contained 12 ppm of extractable phosphorus and 1.3 ppm of extractable zinc.

than were found in the tissue of plants grown on the soil that did not receive phosphorus. The application of zinc did not have a measurable effect on the concentration of phosphorus in plant tissue. The application of zinc to the soil that did not receive phosphorus had no effect on the concentration of zinc in the tissue of the rice plants. When zinc was applied with normal superphosphate, concentrated superphosphate, diammonium phosphate, and monoammonium phosphate, a significantly higher concentration of zinc was found in the plant tissue than was found when these phosphorus sources were applied without supplementary zinc. The application of all of the sources of phosphorus to the soil that did not receive zinc resulted in a small but significant reduction in the zinc content of the tissue of the rice plants. The data suggest that the application of all of the sources of phosphorus resulted in a depression in the concentration of zinc in the plant tissue.

The effects of applications of zinc and different sources of phosphorus on the uptake of phosphorus by Oryza sativa L., cultivar Saturn, grown on unlimed Crowley silt loam, pH 5.3, are presented in Table 18 and in Figure 22. The data indicate that a significant increase in the uptake of phosphorus was obtained when all of the sources of phosphorus were applied to the soil with or without supplementary zinc. When zinc was not used, the application of normal superphosphate resulted in a significantly higher uptake of phosphorus than did the application of the other sources of phosphorus. There was no statistical difference in the uptake of phosphorus by rice plants grown on the soil that received concentrated superphosphate and ammonium polyphosphate when zinc was not applied. The application of diammonium phosphate and monoammonium phosphate to the soil that did not receive zinc resulted in the lowest amounts of phosphorus taken up by the rice plants grown on the Crowley soil. Significantly larger amounts of phosphorus were absorbed from the soil following applications of normal superphosphate and zinc and ammonium polyphosphate and zinc than were absorbed when the other sources of phosphorus were used with zinc. The application of zinc alone to the soil did not result in a significant increase in the amount of phosphorus taken up by the rice plants. The application of zinc with each of the sources of phosphorus resulted in significant increases in the uptake of phosphorus by the rice plants. The largest increases in the uptake of phosphorus occurred on the soils that received phosphorus as normal superphosphate and ammonium polyphosphate.

The data in Table 19 and in Figure 23 show the effects of applications of zinc and different sources of phosphorus on the uptake of zinc by *Oryza sativa* L., cultivar Saturn, grown on unlimed Crowley silt loam, pH 5.3. The application of all of the sources of phosphorus to the soil that did not receive zinc resulted in a significant increase in the uptake of zinc by the rice plants. The application of normal superphosphate alone caused the largest increase in the uptake of zinc. The large amount of zinc taken up by the rice plants from the soil that received normal superphosphate without supplementary zinc may have been due to a small amount of zinc which could have occurred as an impurity in the phosphate rock or in the acid at the time of acidulation. The increased uptake of zinc recorded following the application of all of the sources of phosphorus without supplementary zinc was attributed to the increased growth resulting from the phosphorus treatment. On

Table 18 .- The effects of applications of zinc and different sources of phosphorus on the uptake of phosphorus by Oryza sativa L.,cultivar Saturn, grown on unlimed Crowley silt loam1/, pH 5.3.

Phosphorus sources	Symbol	No Zn	Zn	Difference
		P , µg per pot		
No phosphorus		199	228	29
Normal superphosphate, 8.95% P	NSP	1331	1612	281
Concentrated superphosphate,20.24%P	CSP	1258	1500	242
Diammonium phosphate, 23.32% P	DAP	1054	1279	225
Monoammonium phosphate, 27.82% P	MAP	1079	1317	238
Ammonium polyphosphate, 27.28% P	APP	1243	1546	303
LSD, 5% for P sources:	67			
LSD, 5% for Zn treatments:	52			

1/ The untreated soil contained 12 ppm of extractable phosphorus and 1.3 ppm of extractable zinc.

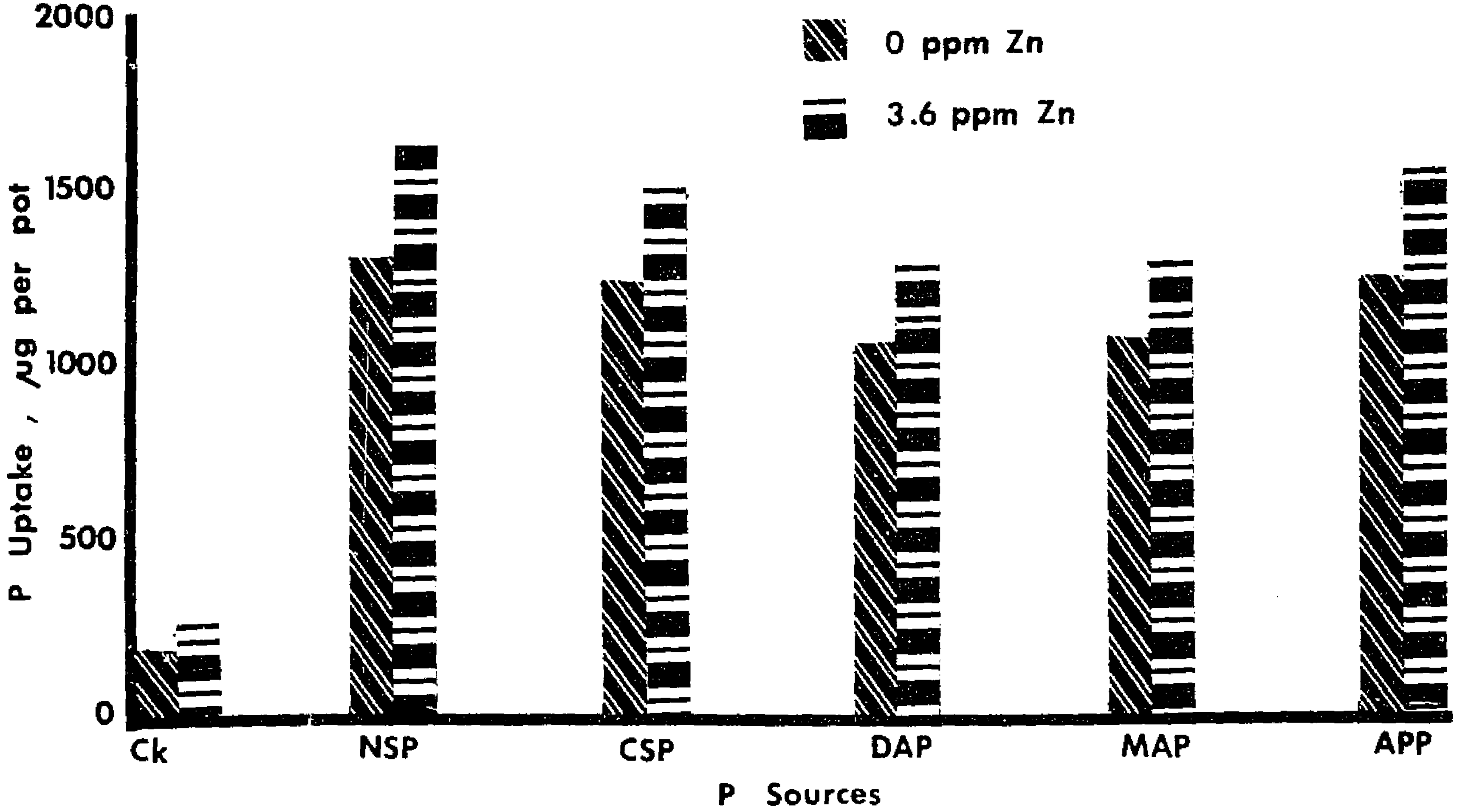

Fig. 22.- The effects of applications of zinc and different sources of phosphorus on the uptake of phosphorus by <u>Oryza sativa</u> L., cultivar Saturn, grown on unlimed Crowley silt loam, pH 5.3.

the soil that received supplementary zinc, the application of normal superphosphate resulted in the highest amount of zinc taken up by the rice plants. The increased uptake of zinc that occurred following the application of normal superphosphate and zinc was attributed to the increased growth of the rice plants. The application of zinc to the soil without added phosphorus resulted in a slight but non-significant increase in the uptake of zinc by the rice plants. Rice plants grown on the soil that did not receive an application of phosphorus were very unthrifty and the production of dry matter was inordinately low regardless of wether or not they received supplementary zinc. The application of zinc with concentrated superphosphate, diammonium phosphate, monoammonium phosphate and ammonium polyphosphate resulted in a significant increase in the uptake of zinc by the rice plants.

The effects of applications of phosphorus and zinc to unlimed and limed Crowley silt loam on the concentration of P, Zn, Fe, Ca and Mg in different plant parts and growth and development phases of _Oryza sativa_ L., cultivar Saturn, are presented in Tables 20 - 35 (Appendix). The effects of applications of phosphorus and zinc to unlimed and limed Crowley silt loam on the ratio of the phosphorus and zinc concentration in the leaf, stem and root of _Oryza sativa_ L., cultivar Saturn, at the vegetative phase of development are presented in Tables 36 and 37 (Appendix). The effects of applications of phosphorus and zinc on the chemical properties of unlimed and limed Crowley silt loam soil at the end of the investigation are presented in Tables 38 and 39 (Appendix). The effects of applications of zinc and different sources of phosphorus on the chemical properties of unlimed Crowley silt loam soil at the end of the investigation are presented in Table 40 (Appendix).

Table 19 .- The effects of applications of zinc and different sources of phosphorus on the uptake of zinc by *Oryza sativa* L., cultivar Saturn, grown on unlimed Crowley silt loam[1/], pH 5.3.

Phosphorus sources	Symbol	No Zn	Zn	Difference
		Zn , μg per pot		
No phosphorus		27	32	5
Normal superphosphate, 8.95% P	NSP	151	199	48
Concentrated superphosphate, 20.24%P	CSP	130	160	30
Diammonium phosphate, 23.32% P	DAP	115	148	33
Monoammonium phosphate, 27.82% P	MAP	120	157	37
Ammonium polyphosphate, 27.28% P	APP	131	155	24

LSD, 5% for P sources: 8
LSD, 5% for Zn treatments: 13

1/ The untreated soil contained 12 ppm of extractable phosphorus and 1.3 ppm of extractable zinc.

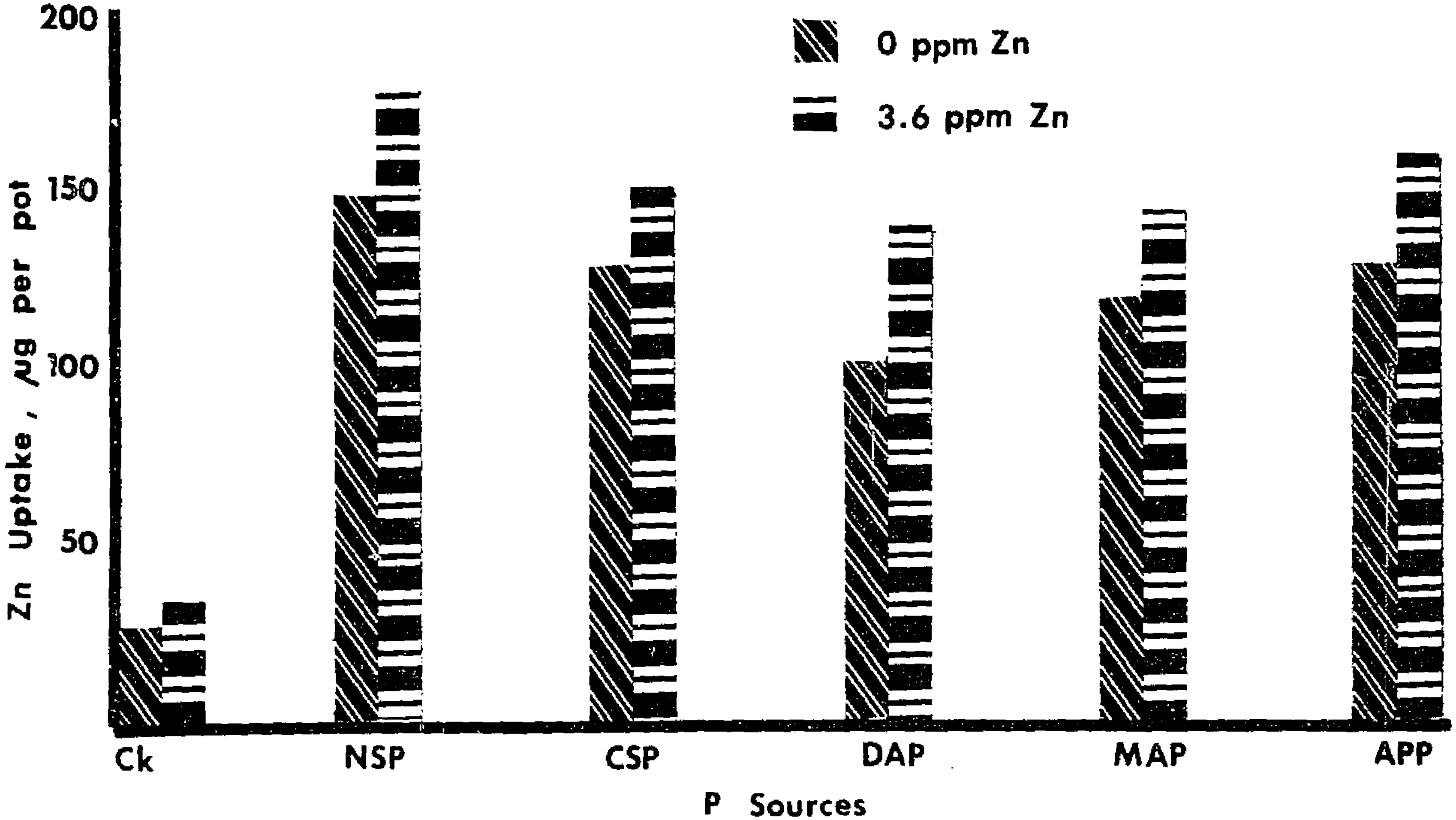

Fig. 23.- The effects of applications of zinc and different sources of phosphorus on the uptake of zinc by *Oryza sativa* L., cultivar Saturn, grown on unlimed Crowley silt loam, pH 5.3.

SUMMARY AND CONCLUSIONS

An investigation was conducted on unlimed and limed Crowley soil to determine the effects of applications of phosphorus and zinc on the production of dry matter of *Oryza sativa* L., cultivar Saturn, at different phases of growth and development. The effects of applications of phosphorus and zinc on the concentration and uptake of phosphorus and zinc, on the ratio of the concentration and uptake of phosphorus and zinc by *Oryza sativa* L., cultivar Saturn, were also studied.

Another investigation was conducted to determine the effects of applications of zinc and different sources of phosphorus on the production of dry matter, the concentration and uptake of phosphorus and zinc in plant tissue of *Oryza sativa* L., cultivar Saturn, at the vegetative phase of growth and development on unlimed Crowley silt loam, pH 5.3.

The application of 50 ppm of phosphorus to the unlimed Crowley silt loam, pH 5.3, resulted in a large significant increase in the production of dry matter of *Oryza sativa* L., cultivar Saturn, at the vegetative, reproductive and ripening phases of growth and development. The application of additional increments of phosphorus above the 50 ppm rate to the unlimed Crowley silt loam soil did not result in further increases in the production of dry matter of rice at the vegetative and reproductive phases. The application of zinc to the soil that did not receive phosphorus had no measurable effect on the production of dry matter of plants at any of the growth phases. There was no significant interaction between the applications of zinc and phosphorus in the total production of dry matter of rice plants and the production of dry matter of rice plants harvested at the vegetative and reproductive growth phases. There was no evidence that application of zinc had any important effect on the growth response of plants to applied phosphorus. High rates of phosphorus had no consistantly depressing effect on the response to applied zinc.

The application of phosphorus resulted in a significant increase over the check in the concentration of phosphorus in the plant tissue. The application of zinc to the unlimed Crowley silt loam soil had no significant effect on the concentration of phosphorus in the plant tissue.

The application of zinc with or without applied phosphorus resulted in a consistant increase in the concentration of zinc in plant tissue. The data indicate that the application of 400 ppm of phosphorus caused a slight but non-significant depression in the concentration of zinc in the tissue of the rice plants.

The application of 50 ppm of phosphorus resulted in a large and significant increase in the uptake of phosphorus by the plants at each of the growth and development phases. Progressive increases in the uptake of phosphorus at all growth phases were noted at each of the five rates of applied phosphorus. The application of four rates of zinc had no significant effect on the uptake of phosphorus by the rice plants harvested at any of the growth phases. Evidence was presented indicating that the application of phosphorus had no depressing effect on the uptake of zinc by plants grown on the unlimed Crowley soil.

The application of 400 ppm of phosphorus to the unlimed Crowley soil resulted in a pronounced increase in the P:Zn ratio in the plant tissue. A variation in the P:Zn ratio from 2.18 to 93.23 was attributed to the phosphorus treatment. The application of zinc to the soil that received phosphorus resulted in a significant reduction in P:Zn ratios calculated from the concentration of phosphorus and zinc in the tissue of plants at the vegetative phase of growth and development.

A consistant increase in the production of dry matter of plants harvested at the vegetative, reproductive and ripening phases of growth was obtained with each of the increments of applied phosphorus to the limed Crowley silt loam, pH 6.3.

The application of zinc alone to the limed soil did not result in a significant increase in the production of dry matter of rice plants harvested at the vegetative and reproductive phases of growth.

A statistically significant interaction was calculated between the phosphorus and zinc treatments and their effects on the production of dry matter of rice plants grown on limed soil at each of the three growth and development phases. The data indicated that the application of high rates of phosphorus did not have a depressing effect on the production of dry matter of plants grown on the limed soil. Severe "bronzing" was observed on plants grown on the limed soil that received the highest rate of phosphorus with and without applied zinc. The concentration of phosphorus in the tissue of the rice plants grown on limed soil that did not receive phosphorus was considered to be critically low at each of the growth and development phases. A statistically significant increase in the concentration of phosphorus in the plant tissue resulted from the application of phosphorus. A statistically significant interaction was obtained between the concentration of phosphorus and zinc in tha tissue of the rice plants at each of the three growth and development phases.

The application of each rate of zinc to Crowley soil pH 6.3 with or without added phosphorus resulted in a consistant increase in the concentration of zinc in the tissue of the rice plants at each of the three growth and development phases. There was a tendency for the higher rates of phosphorus to reduce the concentration of zinc in the tissue of the rice plants at the three growth phases. The data suggest that phosphorus induced zinc deficiency of rice grown under submerged condition may result from the excessive use of phosphorus on Crowley soil at pH 6.3.

A pronounced reduction in the concentration of zinc in the plant tissue was noted with increasing rates of applied phosphorus.

A statistically significant interaction was calculated between the concentration of phosphorus and zinc in the plant tissue.

A very small amount of phosphorus was taken up by the rice plants grown on the soil that did not receive an application of phosphorus. The application of phosphorus resulted in significant increases in the uptake of phosphorus by the rice plants.

The application of zinc to the limed soil that did not receive phosphorus had no effect on the uptake of phosphorus by the rice plants at any of the growth phases. The application of zinc to the soil that received phosphorus resulted in a significant increase in the uptake of zinc by rice plants at each growth phase .

When the Crowley soil was adjusted to pH 6.3 with calcium carbonate, a statistically significant interaction was calculated between the phosphorus and zinc treatments and the uptake of zinc by the rice plants at each of the three growth and development phases. The phosphorus to zinc ratios calculated from the concentration of phosphorus and zinc varied from 0.74 to 111.42. At each rate of applied phosphorus, the application of zinc resulted in a significant decrease in the ratio of the concentration of phosphorus and zinc in the plant tissue.

Normal superphosphate was found to be superior to concentrated superphosphate, diammonium phosphate and monoammonium phosphate but no better than ammonium polyphosphate when no zinc was applied. When zinc was applied, normal superphosphate and ammonium polyphosphate were superior to the other sources of phosphorus in the production of dry matter.

The data show that the application of all of the sources of phosphorus resulted in a depression in the concentration of zinc in the plant tissue.

The largest increase in the uptake of phosphorus occurred on the soils that received normal superphosphate, ammonium polyphosphate and zinc. The largest amount of zinc absorbed by rice plants occurred on soil that received an application of normal superphosphate with and without applied zinc. The application of zinc with concentrated superphosphate, diammonium phosphate, monoammonium phosphate and ammonium polyphosphate resulted in a significant increase in the uptake of zinc by the rice plants.

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APPENDIX

Table 20.- The effects of applications of phosphorus and zinc to unlimed Crowley silt loam[1/], pH 5.3, on the concentration of phosphorus in different plant parts of *Oryza sativa* L., cultivar Saturn, at the vegetative phase of development.

Treatments		Plant parts		
P	Zn	Leaf	Stem	Root
ppm			P, ppm	
0	0	408	430	1330
0	1.8	394	314	825
0	3.6	404	342	1753
0	7.2	342	330	1168
50	0	1140	1356	11098
50	1.8	1136	1480	8130
50	3.6	1270	1430	9668
50	7.2	1308	1414	10870
100	0	1336	1526	9760
100	1.8	1336	1668	8375
100	3.6	1278	1542	10838
100	7.2	1348	1458	10833
200	0	1358	1842	9885
200	1.8	1400	1802	10108
200	3.6	1432	1696	8955
200	7.2	1314	1870	9490
400	0	1812	1984	10073
400	1.8	1662	2148	9348
400	3.6	1738	2136	10005
400	7.2	1822	2084	9720
LSD, 5%		39	48	

1/ The untreated soil contained 12 ppm of extractable phosphorus and 1.3 ppm of extractable zinc.

Table 21 .-The effects of applications of phosphorus and zinc to unlimed Crowley silt loam[1/], pH 5.3, on the concentration of zinc in different plant parts of Oryza sativa L., cultivar Saturn, at the vegetative phase of development.

Treatments		Plant parts		
P	Zn	Leaf	Stem	Root
ppm			Zn, ppm	
0	0	49	57	535
0	1.8	63	61	755
0	3.6	58	64	942
0	7.2	80	90	1316
50	0	40	26	504
50	1.8	49	45	1019
50	3.6	51	44	1076
50	7.2	61	49	1245
100	0	45	28	577
100	1.8	47	41	786
100	3.6	47	38	1175
100	7.2	58	41	1501
200	0	39	25	814
200	1.8	43	30	1106
200	3.6	47	33	1197
200	7.2	47	44	1365
400	0	47	23	910
400	1.8	43	28	895
400	3.6	44	33	1005
400	7.2	49	35	1224
LSD, 5%		15	23	245

[1/]The untreated soil contained 12 ppm of extractable phosphorus and 1.3 ppm of extractable zinc.

Table 22.-The effects of applications of phosphorus and zinc to unlimed Crowley silt loam[1/], pH 5.3, on the concentration of iron in different plant parts of *Oryza sativa* L., cultivar Saturn, at the vegetative phase of development.

Treatments		Plant parts		
P	Zn	Leaf	Stem	Root
ppm		Fe, ppm		
0	0	63	109	43150
0	1.8	90	203	29400
0	3.6	60	226	47925
0	7.2	79	126	31775
50	0	105	114	46900
50	1.8	83	111	49400
50	3.6	168	151	45525
50	7.2	71	124	46150
100	0	70	148	46775
100	1.8	68	126	35775
100	3.6	64	225	41900
100	7.2	165	306	43650
200	0	60	126	40650
200	1.8	80	131	40275
200	3.6	63	121	39650
200	7.2	46	141	43150
400	0	59	106	39775
400	1.8	55	93	34650
400	3.6	65	145	42525
400	7.2	71	124	34275

[1/]The untreated soil contained 12 ppm of extractable phosphorus and 1.3 ppm of extractable zinc.

Table 23.-The effects of applications of phosphorus and zinc on the concentration of iron in plant tissue of *Oryza sativa* L., cultivar Saturn, grown on unlimed Crowley silt loam[1/] pH 5.3, at three growth and development phases.

Treatments		Growth and development phases		
P	Zn	Vegetative[2/]	Reproductive[3/]	Ripening[4/]
ppm			Fe, ppm	
0	0	86	155	230
0	1.8	146	215	217
0	3.6	143	277	327
0	7.2	102	252	247
50	0	109	549	252
50	1.8	97	475	342
50	3.6	159	412	302
50	7.2	97	460	267
100	0	109	585	317
100	1.8	97	530	352
100	3.6	144	315	285
100	7.2	236	507	292
200	0	93	385	232
200	1.8	106	495	275
200	3.6	92	430	347
200	7.2	94	365	290
400	0	82	430	202
400	1.8	74	335	270
400	3.6	105	345	190
400	7.2	97	522	242

[1/]The untreated soil contained 12 ppm of extractable phosphorus and 1.3 ppm of extractable zinc.

[2/]Four plants were harvested 61 days after planting.

[3/]Three plants were harvested 88 days after planting.

[4/]One plant was harvested 125 days after planting.

Table 24.-The effects of applications of phosphorus and zinc to unlimed Crowley silt loam[1/], pH 5.3, on the concentration of calcium in different plant parts of <u>Oryza sativa</u> L., cultivar Saturn, at the vegetative phase of development.

Treatments		Plant parts		
P	Zn	Leaf	Stem	Root
ppm			Ca, ppm	
0	0	5131	3385	25138
0	1.8	4819	3199	29419
0	3.6	4388	2868	26038
0	7.2	4638	3692	38263
50	0	3263	3860	17438
50	1.8	2550	4662	21706
50	3.6	2400	4647	21338
50	7.2	2228	4798	17438
100	0	2138	4398	17208
100	1.8	2681	4337	23000
100	3.6	2644	4093	19669
100	7.2	2312	5289	20350
200	0	2663	5568	15044
200	1.8	2881	4974	16875
200	3.6	2425	5009	22531
200	7.2	2244	5425	20663
400	0	1963	4575	13519
400	1.8	1713	3985	14644
400	3.6	1688	3900	14388
400	7.2	1838	4857	15869

[1/]The untreated soil contained 12 ppm of extractable phosphorus and 1.3 ppm of extractable zinc.

Table 25.-The effects of applications of phosphorus and zinc on the concentration of calcium in plant tissue of *Oryza sativa* L., cultivar Saturn, grown on unlimed Crowley silt loam[1], pH 5.3, at three growth and development phases.

Treatments		Growth and development phases		
P	Zn	Vegetative[2]	Reproductive[3]	Ripening[4]
ppm			Ca, ppm	
0	0	4158	2700	1661
0	1.8	3909	3656	1614
0	3.6	3528	3400	1729
0	7.2	4065	3750	1574
50	0	3461	2800	1927
50	1.8	3506	2966	1876
50	3.6	3423	2587	1930
50	7.2	3412	2919	1959
100	0	3168	2662	1894
100	1.8	3409	2687	2099
100	3.6	3269	2825	1899
100	7.2	3700	2637	1957
200	0	4015	2744	2095
200	1.8	3828	2337	2164
200	3.6	3617	2444	2130
200	7.2	3734	2394	2199
400	0	3169	1881	2477
400	1.8	2749	2087	2392
400	3.6	2694	1887	2341
400	7.2	3247	2006	2485

1/The untreated soil contained 12 ppm of extractable phosphorus and 1.3 ppm of extractable zinc.

2/Four plants were harvested 61 days after planting.

3/Three plants were harvested 88 days after planting.

4/One plant was harvested 125 days after planting.

Table 26.-The effects of applications of phosphorus and zinc to unlimed Crowley silt loam[1/], pH 5.3, on the concentration of magnesium in different plant parts of *Oryza sativa* L., cultivar Saturn, at the vegetative phase of development.

Treatments		Plant parts		
P	Zn	Leaf	Stem	Root
ppm			Mg, ppm	
0	0	1331	1617	10241
0	1.8	1248	2068	8679
0	3.6	1306	1752	8684
0	7.2	1182	2095	8983
50	0	1403	1821	11227
50	1.8	1178	1883	9153
50	3.6	1194	1899	9397
50	7.2	1105	1915	8548
100	0	1016	1807	8066
100	1.8	1199	1903	8594
100	3.6	1275	1863	9338
100	7.2	1184	2189	8591
200	0	1338	2287	10365
200	1.8	1343	2353	10088
200	3.6	1100	2026	8883
200	7.2	1206	2019	8930
400	0	1218	1863	9441
400	1.8	1136	1688	8701
400	3.6	1185	2091	8662
400	7.2	1251	1790	9236

1/The untreated soil contained 12 ppm of extractable phosphorus and 1.3 ppm of extractable zinc.

Table 27.-The effects of applications of phosphorus and zinc on the concentration of magnesium in plant tissue of *Oryza sativa* L., cultivar Saturn, grown on unlimed Crowley silt loam[1], pH 5.3, at three growth and development phases.

Treatments		Growth and development phases		
P	Zn	Vegetative[2]	Reproductive[3]	Ripening[4]
ppm		Mg, ppm		
0	0	1423	1495	1631
0	1.8	1607	1588	1694
0	3.6	1479	1426	1539
0	7.2	1588	1524	1618
50	0	1562	1557	1674
50	1.8	1490	1537	1648
50	3.6	1496	1580	1704
50	7.2	1460	1561	1712
100	0	1361	1395	1547
100	1.8	1500	1387	1503
100	3.6	1519	1362	1473
100	7.2	1636	1473	1681
200	0	1762	1821	1983
200	1.8	1797	1952	1979
200	3.6	1513	1649	1880
200	7.2	1562	2042	1982
400	0	1402	1581	1695
400	1.8	1563	1472	1601
400	3.6	1588	1317	1458
400	7.2	1470	1528	1644

[1]The untreated soil contained 12 ppm of extractable phosphorus and 1.3 ppm of extractable zinc.

[2]Four plants were harvested 61 days after planting.

[3]Three plants were harvested 88 days after planting.

[4]One plant was harvested 125 days after planting.

Table 28-The effects of applications of phosphorus and zinc to limed Crowley silt loam[1/], pH 6.3, on the concentration of phosphorus in different plant parts of Oryza sativa L., at the vegetative stage of development.

Treatments		Plant parts		
P	Zn	Leaf	Stem	Root
ppm			P, ppm	
0	0	228	292	1130
0	1.8	250	222	825
0	3.6	270	318	1698
0	7.2	282	274	1068
50	0	1106	1236	11030
50	1.8	1114	1386	8036
50	3.6	1214	1416	9601
50	7.2	1248	1370	10799
100	0	1152	1454	9703
100	1.8	1092	1546	8299
100	3.6	1238	1498	10793
100	7.2	1244	1370	10785
200	0	1258	1812	9795
200	1.8	1266	1746	10972
200	3.6	1220	1570	8903
200	7.2	1254	1818	9415
400	0	1754	1852	10012
400	1.8	1568	1986	9291
400	3.6	1592	1996	9903
400	7.2	1614	1970	9682
LSD, 5%		12	32	

[1/]The untreated soil contained 12 ppm of extractable phosphorus and 1.3 ppm of extractable zinc.

Table 29.-The effects of applications of phosphorus and zinc to limed Crowley silt loam[1/], pH 6.3, on the concentration of zinc in different plant parts of Oryza sativa L., cultivar Saturn at the vegetative phase of development.

Treatments		Plant parts		
P	Zn	Leaf	Stem	Root
ppm			Zn, ppm	
0	0	28	27	360
0	1.8	35	35	580
0	3.6	43	39	787
0	7.2	51	47	966
50	0	31	19	379
50	1.8	34	32	868
50	3.6	38	33	736
50	7.2	42	36	857
100	0	35	20	515
100	1.8	38	28	636
100	3.6	40	27	1025
100	7.2	46	30	1151
200	0	28	16	628
200	1.8	33	20	931
200	3.6	37	23	997
200	7.2	41	26	1190
400	0	39	14	593
400	1.8	41	18	695
400	3.6	40	23	855
400	7.2	43	24	1097
LSD, 5%		3	3	115

1/The untreated soil contained 12 ppm of extractable phosphorus and 1.3 ppm of extractable zinc.

Table 30.-The effects of applications of phosphorus and zinc to limed Crowley silt loam[1], pH 6.3, on the concentration of iron in different plant parts of *Oryza sativa* L., cultivar Saturn, at the vegetative phase of development.

Treatments		Plant parts		
P	Zn	Leaf	Stem	Root
ppm			Fe, ppm	
0	0	54	99	32254
0	1.8	77	179	14845
0	3.6	58	206	36978
0	7.2	74	116	29995
50	0	66	104	34986
50	1.8	61	99	37785
50	3.6	73	137	44510
50	7.2	67	123	45252
100	0	60	131	45675
100	1.8	58	116	33815
100	3.6	54	172	40972
100	7.2	87	249	42588
200	0	51	102	39865
200	1.8	68	112	39542
200	3.6	53	107	37986
200	7.2	42	127	42950
400	0	49	92	38575
400	1.8	46	81	32956
400	3.6	57	113	41652
400	7.2	62	104	33875

1/The untreated soil contained 12 ppm of extractable phosphorus and 1.3 ppm of extractable zinc.

Table 31.-The effects of applications of phosphorus and zinc on the concentration of iron in plant tissue of <u>Oryza sativa</u> L., cultivar Saturn, grown on limed Crowley silt loam[1/], pH 6.3, at three growth and development phases.

Treatments		Growth and development phases		
P	Zn	Vegetative[2/]	Reproductive[3/]	Ripening[4/]
ppm			Fe, ppm	
0	0	76	125	198
0	1.8	128	187	182
0	3.6	131	239	289
0	7.2	93	217	218
50	0	90	529	231
50	1.8	78	458	319
50	3.6	148	389	288
50	7.2	105	429	239
100	0	99	561	291
100	1.8	96	507	329
100	3.6	124	298	252
100	7.2	215	478	268
200	0	84	367	211
200	1.8	91	459	249
200	3.6	78	398	317
200	7.2	81	241	269
400	0	74	393	180
400	1.8	66	317	228
400	3.6	95	321	158
400	7.2	89	498	218

1/The untreated soil contained 12 ppm of extractable phosphorus and 1.3 ppm of extractable zinc.

2/Four plants were harvested 61 days after planting.

3/Three plants were harvested 88 days after planting.

4/One plant was harvested 125 days after planting.

Table 32.-The effects of applications of phosphorus and zinc to limed Crowley silt loam[1], pH 6.3, on the concentration of calcium in different plant parts of *Oryza sativa* L., cultivar Saturn, at the vegetative phase of development.

Treatments		Plant parts		
P	Zn	Leaf	Stem	Root
ppm			Ca, ppm	
0	0	5433	3685	28232
0	1.8	5121	3499	32407
0	3.6	4700	3168	29139
0	7.2	4937	3992	41267
50	0	3541	4160	20473
50	1.8	2851	4886	24807
50	3.6	2706	4871	24437
50	7.2	2528	5097	20538
100	0	2447	4697	20309
100	1.8	2991	4632	26015
100	3.6	2929	4365	22703
100	7.2	2616	5513	23358
200	0	2968	5868	18058
200	1.8	3185	5274	19895
200	3.6	2728	5309	25638
200	7.2	2545	5744	23687
400	0	2262	4875	16629
400	1.8	2012	4284	17734
400	3.6	1987	4200	17492
400	7.2	2137	5157	18869

1/The untreated soil contained 12 ppm of extractable phosphorus and 1.3 ppm of extractable zinc.

Table 33.-The effects of applications of phosphorus and zinc on the concentration of calcium in plant tissue of *Oryza sativa* L., cultivar Saturn, grown on limed Crowley silt loam[1], pH 6.3, at three growth and development phases.

Treatments		Growth and development phases		
P	Zn	Vegetative[2]	Reproductive[3]	Ripening[4]
ppm		Ca, ppm		
0	0	4559	3000	2061
0	1.8	4310	3931	2013
0	3.6	3934	3700	2128
0	7.2	4464	4050	1973
50	0	3850	3100	2327
50	1.8	3868	3266	2176
50	3.6	3789	3137	2330
50	7.2	3813	3218	2358
100	0	3572	2962	2293
100	1.8	3813	2987	2498
100	3.6	3648	3100	2298
100	7.2	8129	2937	2357
200	0	4418	3043	2495
200	1.8	4229	2637	2563
200	3.6	4018	2743	2530
200	7.2	4145	2693	2598
400	0	3568	2181	2877
400	1.8	3148	2387	2792
400	3.6	3093	2181	2741
400	7.2	3647	2306	2935

[1]/The untreated soil contained 12 ppm of extractable phosphorus and 1.3 ppm of extractable zinc.

[2]/Four plants were harvested 61 days after planting.

[3]/Three plants were harvested 88 days after planting.

[4]/One plant was harvested 125 days after planting.

Table 34.-The effects of applications of phosphorus and zinc to limed Crowley silt loam[1/], pH 6.3, on the concentration of magnesium in different plant parts of *Oryza sativa* L., cultivar Saturn, at the vegetative phase of development.

Treatments		Plant parts		
P	Zn	Leaf	Stem	Root
ppm			Mg, ppm	
0	0	1326	1611	10245
0	1.8	1246	2016	8682
0	3.6	1303	1754	8680
0	7.2	1178	2097	8986
50	0	1399	1822	11229
50	1.8	1176	1881	9152
50	3.6	1192	1896	9395
50	7.2	1103	1914	8547
100	0	1011	1808	8064
100	1.8	1195	1903	8595
100	3.6	1273	1865	9336
100	7.2	1181	2186	8592
200	0	1337	2286	10362
200	1.8	1341	2352	10082
200	3.6	1104	2018	8884
200	7.2	1211	2018	8931
400	0	1215	1860	9440
400	1.8	1136	1685	8703
400	3.6	1183	2089	8658
400	7.2	1248	1787	9232

[1/]The untreated soil contained 12 ppm of extractable phosphorus and 1.3 ppm of extractable zinc.

Table 35.-The effects of applications of phosphorus and zinc on the concentration of magnesium in plant tissue of *Oryza sativa* L., cultivar Saturn, grown on limed Crowley silt loam[1], pH 6.3, at three growth and development phases.

Treatments		Growth and development phases		
P	Zn	Vegetative[2]	Reproductive[3]	Ripening[4]
ppm		Mg, ppm		
0	0	1420	1490	1635
0	1.8	1603	1589	1695
0	3.6	1480	1428	1535
0	7.2	1585	1522	1615
50	0	1563	1558	1673
50	1.8	1487	1535	1646
50	3.6	1495	1574	1705
50	7.2	1458	1563	1714
100	0	1359	1397	1549
100	1.8	1495	1385	1500
100	3.6	1520	1360	1474
100	7.2	1634	1475	1679
200	0	1760	1820	1981
200	1.8	1799	1950	1977
200	3.6	1511	1652	1878
200	7.2	1560	2044	1983
400	0	1404	1583	1697
400	1.8	1564	1470	1606
400	3.6	1586	1315	1452
400	7.2	1471	1525	1641

[1] The untreated soil contained 12 ppm of extractable phosphorus and 1.3 ppm of extractable zinc.

[2] Four plants were harvested 61 days after planting.

[3] Three plants were harvested 88 days after planting.

[4] One plant was harvested 125 days after planting.

Table 36.-The effects of applications of phosphorus and zinc to unlimed Crowley silt loam[1/], pH 5.3, on the ratio of phosphorus-zinc concentration in leaf, stem and root of *Oryza sativa* L., cultivar Saturn, at the vegetative phase of development.

Treatments		Plant parts		
P	Zn	Leaf	Stem	Root
ppm		P:Zn ratio		
0	0	4.16	3.77	2.49
0	1.8	3.13	2.57	1.09
0	3.6	3.48	2.67	1.86
0	7.2	2.14	1.83	0.89
50	0	14.25	26.08	22.02
50	1.8	11.59	16.44	7.98
50	3.6	12.45	16.25	8.98
50	7.2	10.72	14.43	8.73
100	0	14.84	27.25	16.92
100	1.8	14.21	20.34	10.66
100	3.6	13.60	20.29	9.22
100	7.2	11.62	17.78	7.22
200	0	17.41	36.84	12.14
200	1.8	16.28	30.03	9.14
200	3.6	15.23	25.70	7.48
200	7.2	13.98	21.25	6.95
400	0	19.28	43.13	11.07
400	1.8	19.33	38.36	10.44
400	3.6	19.75	32.36	9.96
400	7.2	18.59	29.77	7.94

[1/]The untreated soil contained 12 ppm of extractable phosphorus and 1.3 ppm of extractable zinc.

Table 37.-The effects of applications phosphorus and zinc to limed Crowley silt loam1/ pH 6.3, on t ratio of phorus-zinc concentration in leaf, stem and roo f *Oryza s a* L., cultivar Saturn, at the vegetative phase developmen

Treatments		Plant parts		
P	Zn	Leaf	Stem	Root
ppm		P:Zn ratio		
0	0	4.07	5.41	3.14
0	1.8	3.57	3.17	1.42
0	3.6	3.14	4.08	2.16
0	7.2	2.76	2.91	1.11
50	0	17.84	32.53	29.10
50	1.8	16.38	21.66	9.26
50	3.6	15.97	21.45	13.04
50	7.2	14.86	19.03	12.60
100	0	16.46	36.35	18.84
100	1.8	14.37	27.61	13.05
100	3.6	15.48	27.74	10.53
100	7.2	13.52	22.83	9.37
200	0	22.46	56.63	15.60
200	1.8	19.18	43.65	11.79
200	3.6	16.49	34.13	8.93
200	7.2	15.29	34.96	79.12
400	0	22.49	66.14	16.88
400	1.8	19.12	55.17	13.37
400	3.6	19.90	43.39	11.58
400	7.2	18.77	41.04	8.83

1/The untreated soil contained 12 ppm of extractable phosphorus and 1.3 ppm of extractable zinc.

Table 38.- The effects of applications of phosphorus and zinc on the chemical properties of unlimed Crowley silt loam1/, pH 5.3, at the end of the investigation.

Treatments		Extractable				
P	Zn	P2/	Zn3/	Ca4/	Mg4/	K4/
ppm				ppm		
0	0	12	1.98	858	203	90
0	1.8	11	2.74	855	200	104
0	3.6	12	3.52	823	191	96
0	7.2	11	4.54	843	192	98
50	0	14	3.46	833	191	24
50	1.8	16	3.46	823	194	34
50	3.6	15	4.10	900	202	35
50	7.2	15	4.61	823	185	26
100	0	50	2.81	885	187	30
100	1.8	44	3.13	863	185	34
100	3.6	58	3.18	933	201	29
100	7.2	47	4.53	855	182	34
200	0	110	2.88	938	208	41
200	1.8	104	3.42	915	211	31
200	3.6	127	3.72	888	208	26
200	7.2	165	4.27	885	195	26
400	0	293	2.43	783	181	25
400	1.8	202	2.86	855	184	39
400	3.6	220	3.24	918	218	33
400	7.2	241	3.67	908	214	28

1/The untreated soil contained 12 ppm of extractable phosphorus and 1.3 ppm of extractable zinc.

2/Phosphorus was extracted with 0.1 N HCl containing 0.03 N NH_4F at a soil to extracting solution ratio of 1:20.

3/Zinc was extracted with 0.1 N HCl at a soil to extracting solution ratio of 1:10.

4/Calcium, magnesium and potassium were extracted with 0.1 N HCl at a soil to extracting solution ratio of 1:20.

Table 39.-The effects of applications of phosphorus and zinc on the chemical properties of limed Crowley silt loam[1], pH 6.3, at the end of the investigation.

Treatments		Extractable				
P	Zn	P[2]	Zn[3]	Ca[4]	Mg[4]	K[4]
ppm				ppm		
0	0	18	1.15	1150	201	68
0	1.8	18	2.25	1180	187	76
0	3.6	17	2.94	1090	184	65
0	7.2	17	4.03	1200	165	60
50	0	27	2.26	1220	162	35
50	1.8	26	2.88	1290	176	31
50	3.6	29	3.52	1320	180	31
50	7.2	33	4.05	1250	153	49
100	0	58	2.10	1300	160	26
100	1.8	48	2.82	1240	168	26
100	3.6	50	2.91	1250	184	24
100	7.2	44	3.43	1150	173	23
200	0	85	1.98	1150	181	25
200	1.8	75	2.68	1100	194	23
200	3.6	74	2.95	1160	199	21
200	7.2	104	3.52	1140	178	26
400	0	174	1.86	1220	207	25
400	1.8	162	2.09	1150	195	23
400	3.6	178	2.85	1170	198	23
400	7.2	199	3.01	1180	192	25

[1]The untreated soil contained 12 ppm of extractable phosphorus and 1.3 ppm of extractable zinc.

[2]Phosphorus was extracted with 0.1 N HCl containing 0.03 N NH_4F at a soil to extracting solution ratio of 1:20.

[3]Zinc was extracted witn 0.1 N HCl at a soil to extracting solution ratio of 1:10.

[4]Calcium, magnesium and potassium were extracted with 0.1 N HCl at a soil to extracting solution ratio of 1:20.

Table 40.-The effects of applications of different sources of phosphorus on the chemical properties of unlimed Crowley silt loam[1], pH 5.3, at the end of the investigation.

P Sources	Extractable P No Zn	Extractable P Zn	Extractable Zn No Zn	Extractable Zn Zn	Extractable K No Zn	Extractable K Zn	Extractable Ca No Zn	Extractable Ca Zn	Extractable Mg No Zn	Extractable Mg Zn
	ppm									
Check	11	13	1.85	1.98	68	69	608	603	207	207
Normal Superphosphate	34	29	1.53	1.81	28	26	705	690	205	205
Concentrated superphosphate	32	41	1.62	1.79	35	40	615	640	204	204
Diammonium phosphate	42	43	1.58	1.64	34	29	618	598	209	201
Monoammonium phosphate	36	50	1.49	1.54	33	34	608	578	206	196
Ammonium poly-phosphate	37	40	1.45	1.52	25	29	593	580	205	198

[1]The untreated soil contained 12 ppm of extractable phosphorus and 1.3 ppm of extractable zinc.

VITA

Nguyen Bich Lieu was born on September 25, 1940 at Cholon, South Viet Nam. She was graduated from Gia Long High School, Saigon, in 1959.

She entered the National College of Agriculture in Saigon in 1960 and was graduated in 1963 receiving an Engineer in Agriculture degree (B. S. in Agriculture).

She worked as a staff member of the College of Agriculture in Saigon from 1963 to 1966.

In 1966, she came to the United States and joined Louisiana State University as a graduate student in the Department of Entomology. She graduated in August 1968 receiving a Master of Science degree. She joined the Department of Agronomy in September 1968 and she is presently a candidate for the degree of Doctor of Philosophy in the Department of Agronomy.

EXAMINATION AND THESIS REPORT

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Title of Thesis: The effects of applications of phosphorus and zinc on growth and nutrient uptake by rice, Oryza sativa L., cultivar Saturn.

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